REPORT JTCG/AS-94-D-002
LMI REPORT JL301RD1

JTCG/AS

Revision 1

AIRCRAFT BATTLE DAMAGE REPAIR (BDR) ANALYSIS METHODOLOGY DEVELOPMENT REQUIREMENTS

1 NOVEMBER 1994

Prepared by the
Logistics Management Institute
for the
Joint Technical Coordinating Group
on Aircraft Survivability (JTCG/AS)
Central Office

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

REPORT DOCUMENTATION PAGE

Form Approved OPM No.0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1 November 1994	Research Document

4. TITLE AND SUBTITLE

Revision 1 — Aircraft Battle Damage Repair (BDR) Analysis Methodology Development Requirements

5. FUNDING NUMBERS

C MDA903-90-C-0006

PE 0902198D

6. AUTHOR(S)

Bruce J. Kaplan
D. Jerry Wallick

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Logistics Management Institute
2000 Corporate Ridge
McLean, VA 22102-7805

8. PERFORMING ORGANIZATION REPORT NUMBER

LMI–JL301RD1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

JTCG/AS Central Office
Commander, Naval Air Systems Command
AIR — 4.1.8 JTCG/AS CO
1421 Jefferson Davis Highway
Arlington, VA 22243-5120

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

JTCG/AS-94-D-002

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

A: Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The JTCG/AS has been asked by the Office of the Secretary of Defense (OSD) to develop and implement a DoD accepted analysis methodology to address BDR aspects of aircraft system design, development, and acquisition. A BDR analysis methodology workshop was conducted to investigate feasible extensions of existing survivability and logistics support analysis methods to include BDR. No methodology obstacles were identified which would preclude such extensions. Industry and government organizations were visited and solicited for specific details on existing methodology limitations that must be addressed to incorporate appropriate BDR considerations. This report summarizes findings from these visits and interviews and documents a recommenderd roadmap with near-, mid-, and long-term tasks and projects for developing the required BDR analysis capability.

14. SUBJECT TERMS

Battle Damage Repair, BDR, BDR Analysis, Damage Prediction, Damage Assessment, Repair Time, Sortie Generation, Sustainment, Force Multiplication, BDAR, Combat Maintenance, Return-to-Combat-Rate

15. NUMBER OF PAGES

69

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298, (Rev. 2-89)
Prescribed by ANSI Std. 239-18
299-01

Contents

List of Figures

EXECUTIVE SUMMARY

Early in 1991, the Office of the Secretary of Defense (OSD) initiated a program for the development and implementation of a DoD accepted analysis methodology to address the battle damage repair (BDR) aspects of weapon system design, development, and acquisition. The Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) was tasked by OSD to take the lead in establishing these analysis methods for aircraft. LMI was then asked by the JTCG/AS to research the status of aircraft BDR analysis and establish a detailed plan of action through which a DoD accepted aircraft BDR analysis methodology could be developed. Three options were available for addressing the aircraft BDR methodology development problem:

- Extend the existing analysis methods used in closely related aircraft system engineering disciplines to address BDR issues and analytical requirements

- Adapt and/or extend analysis methods used for ground combat vehicle battlefield damage assessment and repair to aircraft BDR analysis

- Establish a new methodology for aircraft BDR analysis.

Initial information gathering was done through a "government only" aircraft BDR analysis methodology workshop. Participants included 47 Army, Navy, and Air Force engineers and analysts directly involved in BDR, survivability, and/or logistics support analysis (LSA), three closely related and interdependent system engineering disciplines. *A major finding from the workshop was that there were no known methodology obstacles to preclude proceeding with BDR in weapon system acquisition.* Participants agreed that an accepted BDR analysis methodology could be developed by expanding existing methodologies for survivability analysis and for LSA. These findings supported the preliminary conclusion that the first option listed above was the most cost effective approach to aircraft BDR analysis methodology development. Details of workshop discussions and findings are contained in Report JTCG/AS-92-D-004 (LMI Report JL201RD3), *Report on Joint Service Aircraft Battle Damage Repair (BDR) Analysis Methodology Workshop*, 22 September 1992.

A workshop follow-on effort was initiated to more specifically define BDR analysis methodology requirements, current capabilities, and development needs based on identified voids. Industry and additional government inputs were solicited through an extensive series of visits and interviews. The following key conclusions resulted from the interviews:

- BDR is generally recognized as a viable consideration by industry and government organizations participating in aircraft system acquisition.

- No consistent or comprehensive approach to BDR engineering, and particularly BDR analysis, exists.

- BDR is usually, but not always, assigned to the maintainability/logistics support organization in the system development process.

- Consideration for BDR, primarily BDR technique identification, generally starts late in Dem/Val phase as "planning" with no real work done until well into Engineering and Manufacturing Development phase. This precludes incorporation of design alternatives for BDR enhancement. The primary reason is that there are currently no practical and accepted analytical methods to perform design trade studies for BDR.

- Major input from the survivability community is incorporated in most BDR activities, primarily as damage level prediction and system response (i.e., "kill category") prediction as part of BDR technique identification.

- An accepted DoD analysis methodology for BDR is needed and would be welcomed by industry. Discussions with industry BDR engineers and analysts indicate that they are struggling with the problem of how to quantify BDR characteristics in order to meet specified system goals or requirements and to perform design trade studies that include BDR considerations. However, they also emphasize the need for BDR analysis methodologies to be practical. The preference is that BDR analysis be the simplest possible extensions of survivability and logistics support analyses. They do not want imposition of methods that require extraordinary expenditures of manpower, computer hardware or software investment, or run time. The damage assessment methodology should also be the same for BDR as for vulnerability analysis. For example, if vulnerability analysis requires COVART 2, do not require COVART 3 for BDR.

Based on the findings of the workshop, results of the visit/interview effort, and input received at JTCG/AS and various other system analysis methodology development meetings and conferences, the following recommendations are made:

- Establish a hierarchy of BDR analysis to guide the level of detail required for specific analyses.

- Define a BDR analysis process which specifies BDR analysis tasks and the analytical interfaces with survivability and LSA procedures.

- Integrate BDR analysis as an extension of DoD accepted survivability analysis methods for damage prediction and as an extension of DoD accepted logistics support analysis (LSA) methods for repair analysis.

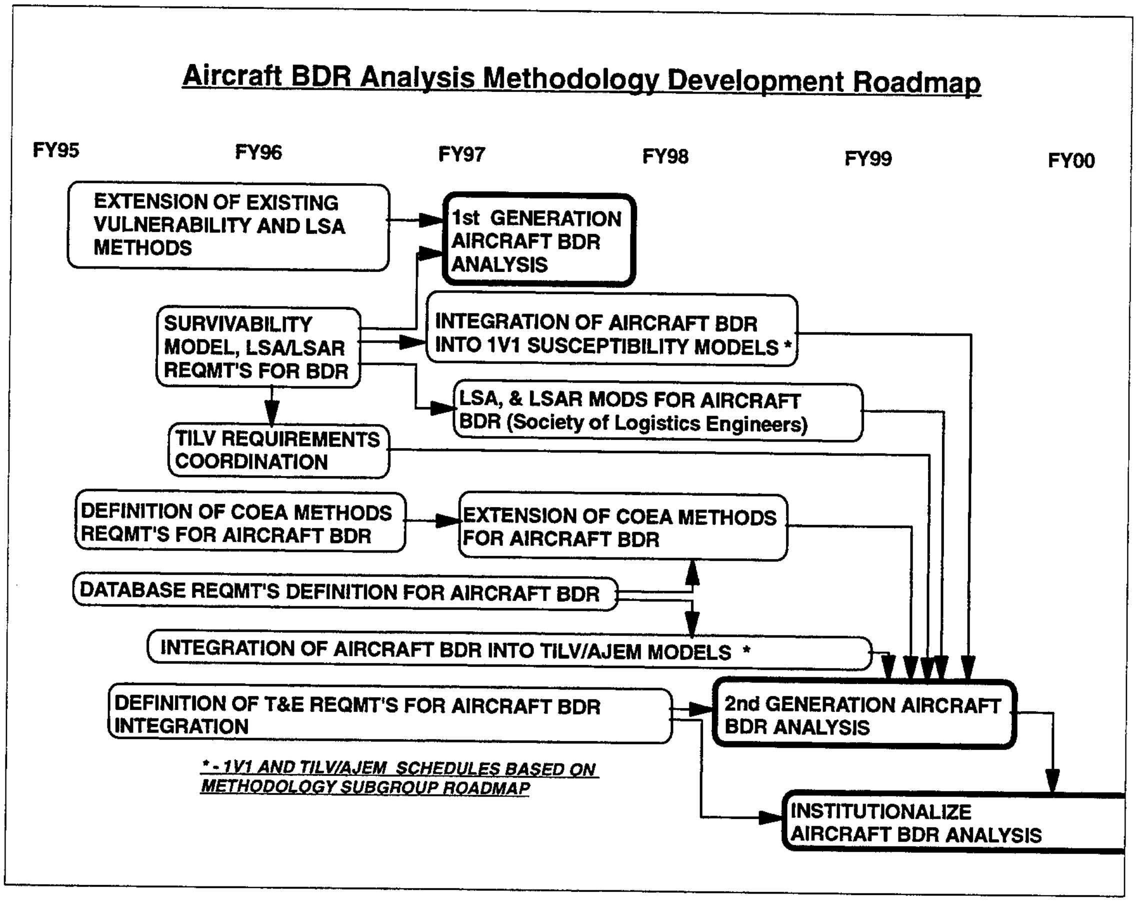
- In the near term, develop BDR analysis methodology based on currently available damage prediction methods and LSA repair analysis methods.

- Establish longer range BDR analysis methodology development tasks based on proposed damage prediction methods and LSA repair analysis methods.

- Coordinate BDR model development with the establishment of DoD accepted modeling and simulation environment(s) (e.g., Digital Integrated Modeling Environment or Joint Modeling and Simulation System) in the same manner that

JTCG/AS Survivability Methodology Subgroup models are envisioned to be handled.

The recommended roadmap for developing and implementing a DoD accepted aircraft BDR analysis methodology is shown in the following figure.



The recommended approach is to develop a critically needed 1st generation capability based on extensions of existing survivability and logistics support analysis methods. Additionally, BDR analysis requirements need to be coordinated with, or integrated into, ongoing development of advanced analysis methods. A 2nd generation capability would evolve from this effort and would be the baseline for institutionalization of aircraft BDR analysis. Susceptibility and vulnerability model integration schedules are consistent with the JTCG/AS Methodology Subgroup roadmap. Revitalized coordination with the LSA community will be required. One or more workshops on aircraft BDR analysis methods are envisioned to coordinate progress.

Task Schedule for Aircraft BDR Analysis Methodology Development

	FY95	FY96	FY97	FY98	FY99	FY00	
Near-term Tasks (1st Generation BDR Analysis Capability)							
1. Component Numbering System for BDR							
2. Repair Time Analysis Extension for On-aircraft Repair							
3. Survivability Model Extensions for Aircraft BDR							
4. Aircraft BDR Interface into LSA/LSAR							
Mid-term Tasks (2nd Generation BDR Analysis Capability)							
5. BDR Integration with Higher Level Models							
6. Test & Evaluation Guidelines for BDR							
7. Aircraft BDR Database Development							
8. LSA Expansion for BDR							
9. Sensitivity Analyses on 1st Generation BDR Methodology							
10. Integration of BDR into AJEM							
Long-term Tasks (Institutionalizing BDR Analysis)							
11. SURVIAC Entry of Aircraft BDR Analysis Methodology							
12. Publish DoD Accepted Aircraft BDR Analysis Methodology				▽	1st gen.	2nd gen.	▽
13. Aircraft BDR Modeling Update							

As indicated in the above figure, near-, mid-, and long-term tasks have been identified to implement the recommended roadmap. This phased approach is intended to provide a reasonable capability to perform design trade studies for BDR in the near term, an urgently needed tool. The 2nd generation capability is then developed under the mid-term tasks. The eventual institutionalization of BDR analysis, a long-term objective, will depend upon formalizing analytical methods, establishing appropriate databases, and publishing educational materials of various kinds to promulgate the discipline. The institutionalization process will be a continuing effort to maintain state-of-the-art BDR analysis capabilities as is done for all system engineering disciplines.

Chapter 1. Introduction

The Office of the Under Secretary of Defense for Acquisition and Technology/Tactical Warfare Programs/Air Warfare [OUSD(A&T)/TWP(AW)] and the JTCG/AS have initiated an effort to establish BDR as a system design discipline. A critical element of this initiative is the development of the technologies to provide materials, tools, and repair procedures to quickly return combat damaged aircraft to service. An equally important part of design discipline development is the establishment of acceptable analysis methods to provide system designers and managers with credible BDR related information for performing design trade studies and system effectiveness analyses and for establishing operational support requirements.

In support of this initiative, LMI was asked by the JTCG/AS to research BDR analysis methods and recommend a plan of action to develop a DoD accepted BDR analysis methodology. A BDR analysis methodology development workshop was conducted to establish the feasibility of developing a DoD accepted BDR analysis methodology. Workshop participants included representatives from the Army, Navy, and Air Force who possessed expertise in aircraft BDR and the related fields of survivability and logistics support. *The major finding of the workshop was that there are no known methodology obstacles that would preclude proceeding with the process of including BDR in weapons development.* Workshop attendees also agreed that BDR does fit as a logical extension of the survivability and integrated logistics support (ILS) disciplines. However, modifications to current practices and methods are needed to bridge the gap between totally peacetime-oriented logistics support analysis (LSA) and wartime-oriented survivability analysis. The findings of the workshop were formulated into an action plan to develop, implement, and maintain a DoD accepted aircraft BDR analysis methodology.

A three-phased approach was recommended to and accepted by the JTCG/AS and the OSD sponsor for establishing Aircraft BDR Analysis as an integral part of system engineering analysis. Phase I would define a detailed roadmap for BDR methodology development and specific work packages for aircraft BDR methodology development. Phase II would be doing the BDR methodology development work defined in Phase I. Phase III would be the institutionalization of Phase II results (i.e., make BDR analysis an integral part of the weapon system engineering and effectiveness analysis process). As envisioned, Phases II & III would be continuing efforts to modify, upgrade, expand, and validate the methodology as technology and warfighting strategies evolve, just as with other system analysis methods.

This report represents work accomplished thus far under Phase I. It defines a recommended BDR analysis methodology development roadmap compiled through extensive workshop follow-up interviews and meetings with both government and industry representatives familiar with BDR and BDR-related disciplines. This roadmap, along with the follow-on effort to develop the details of specific work packages for BDR methodology development, will constitute Phase I of the general BDR methodology development plan.

Chapter 2. Aircraft Battle Damage Repair (BDR) Analysis

This chapter outlines a recommended conceptual approach for defining aircraft BDR analysis as it relates to the various levels of analysis which must explicitly address BDR during the system acquisition life cycle.

2.1 Objectives of BDR Analysis

The primary objective of aircraft BDR is to increase the capability of our military Services to quickly return battle damaged weapon systems to combat. Aircraft BDR analysis objectives are to provide the quantitative analytical data through which system design and operational support are accomplished to meet overall BDR objectives. BDR analyses should provide useful BDR related data to system designers, logistics and operational support personnel, and system program managers. This requirement leads to a logical hierarchy of analysis for BDR as discussed in section 2.2 and shown in Figure 2.1. The objectives for BDR analysis will be fulfilled when DoD accepted/accredited methodologies are available to meet the following needs:

For system designers -

1. Determine battle damage frequency, location, and level/severity of the damage

2. Identify areas on the vehicle (including skin, primary structures, sub-structures, and interior components/equipment) that:

- Cannot be repaired under existing BDR constraints (i.e., repair techniques are not available, repairs require depot level capabilities that cannot be deployed to the field, etc.)
- Take a long time to do BDR
- Are hard to assess either in the damaged condition to determine required repair or after repair to determine mission capability
- Are hard to fix in the field
- Need special care (e.g., clean-room conditions, special equipment, etc.) to repair
- Take little time to do BDR
- Are not critical to performing the "next mission"
- Need only cosmetic repair to be mission capable
- Can be easily & safely bypassed

3. Compare alternatives during design trade studies to identify preferred design for ease of repair and integrity of the repair.

4. Identify high risk technologies incorporated into the system design. These would be technologies for which there are no existing repair techniques, technologies that require depot level capabilities for repair of expected damage, expensive spares would have to be stocked to replace nonrepairable damaged components/subsystems, etc.

5. Provide properly formatted data to higher level analyses such as system effectiveness analyses, logistics supportability analyses, and cost and operational effectiveness analyses.

6. Use parameters that can be verified/tested

7. Identify equipment and material needs (interface with logistics support and assess overall system BDR characteristics) for:

- Damage assessment: test, measurement, and diagnostics equipment (TMDE)
- Repair: tools, equipment, facilities, materials, and spares

8. Identify personnel needs (interface with logistics support and assess overall BDR characteristics)

- Skills (specialty codes)
- Workload

For logistics and operational support -

1. Provide input to manpower/personnel/training (MPT) such as:

- Manning level for combat maintenance
- Skills for combat maintenance
- Training for BDR (initial & refresher, class room & lab/hands-on, O/I/D level, engineer & technician)

2. Develop authorizations for provisioning (spares, repair parts, war reserves)

3. Identify requirements for ground support equipment (GSE), tools, repair kits, etc.

4. Identify high risk items associated with MPT , provisioning, and/or GSE for BDR

5. Define level of damage beyond which labor and/or dollar costs to repair exceed established maintenance expenditure limits (MELs).

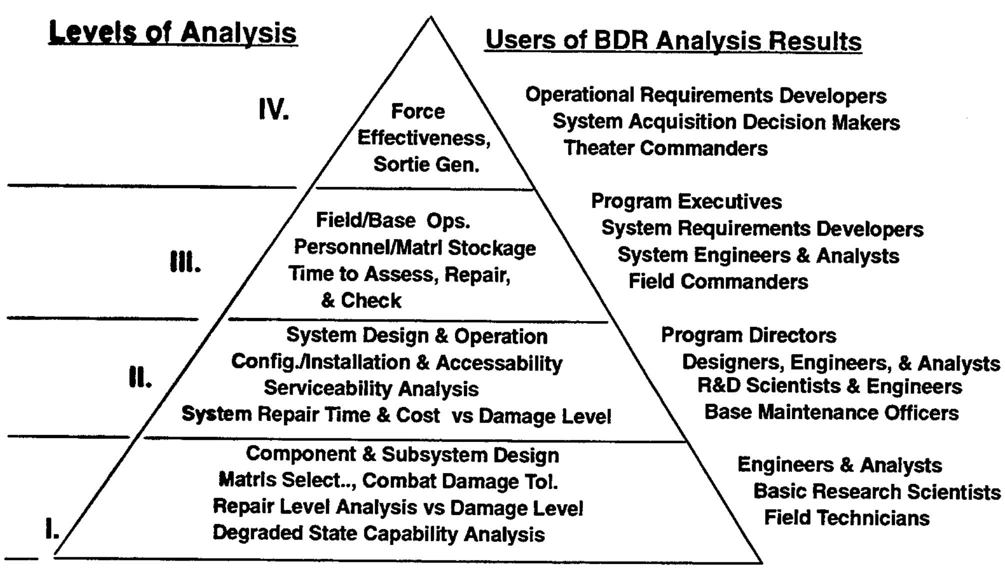
For system program management -

Another important objective for BDR analysis is to provide valid information for input to higher level analyses such as system effectiveness evaluations and cost and operational effectiveness analyses (COEAs). This information is critical so that program managers and DoD decision makers can assess the potential payoff in warfighting capability or force multiplication effects of incorporating system design and/or logistics operational concepts that enhance system BDR capabilities. Good system design and supportability concepts for BDR lead to sustained combat capability given survivable damage. On the other hand, incorporation of poor BDR design and support concepts can result in total loss of warfighting capability given rather minor combat damage. The sustainability benefits of good BDR and, conversely, the effective attrition of poor BDR need to be visible in COEAs.

2.2 Hierarchy of Analysis

Figure 2.1. outlines a conceptual hierarchy of BDR analysis for addressing the various levels of analytic detail needed to meet the above requirements. The 4 levels of detail for BDR analysis depicted in Figure 2.1 are consistent with those generally accepted for system engineering analysis disciplines including survivability.

Figure 2.1 Hierarchy of Aircraft BDR Analysis



The level of physical detail needed to analyze BDR is the highest in Level I. As analyses proceed up the hierarchy, the physical detail is reduced and overall system characteristics are introduced. This hierarchy can be used also to allocate BDR requirements from the top down. As system design evolves, iterations should be made to assess the impact of various design details on the higher Level system BDR characteristics and to track compliance with the requirements. The following discussion summarizes the basic considerations at the various levels of analysis within the hierarchy. Further details are covered in APPENDIX B.

Level I Analysis

Level I BDR analysis is conducted at the component level and addresses the inherent design characteristics of the component which affect repairability in the field. These characteristics include things such as material selection, component interchangeability, and markings for ease of identification. Although, the level of physical detail needed to analyze BDR is the highest in Level I, the decisions made at the component design level can greatly affect the overall system design for repairability. A Level I BDR analysis is analogous to survivable component design analysis (e.g., rip-stop or jam-resistant hydraulic actuators, multi-spar wings, toughened epoxy composite materials, etc.).

To a great extent, Level I BDR analyses might be considered good, common sense design analyses. However, if they are not explicitly conducted, poor BDR design can, and often does, result. Documentation of Level I analyses can also provide data for input to Level II analyses.

Level II Analysis

Level II BDR analysis deals with platform or vehicle design considerations to enhance BDR capabilities. It is comparable to survivability analyses that address a single operating aircraft as it encounters a single operating threat system. These are usually referred to as "platform" or "1 on 1" analyses. Level II is the lowest level at which overall vehicle design trade studies are made. Comparable Level II survivability analyses would be calculation of aircraft vulnerable area (A_V) versus a specific threat (e.g., COVART) or aircraft probability of kill (P_K) versus a specific threat (e.g., ESAMS).

Several efforts to develop Level II BDR models were, or are being, undertaken with none being totally successful. These include COVART which is continually being developed by various organizations, the SCANMOD/REPAIR model development by the Air Force at Wright-Patterson AFB, OH, and the degraded states vulnerability methodology being developed by the Army Research Laboratory at Aberdeen Proving Ground, MD.

Level III Analysis

Level III BDR analyses are base level analyses that address issues related to BDR during combat operations on a base or carrier. Several types of aircraft would be flying various missions against an array of threats. Level III BDR analyses are comparable to survivability analyses that address multiple aircraft encountering multiple threats, ground based and/or airborne. In the survivability community, these are referred to as "few-on-few" or "M-on-N" analyses which are used to assess targets killed versus aircraft lost or

exchange ratios. Examples of Level III aircraft survivability models are TAC Brawler, an Air Force developed model, and tactical mission analysis system (TMAS), used by Bell Helicopter/Textron. The Air Force has used a scenario based model, Logistics Composite Model (LCOM), to assess sortie generation rate from recovery to take-off, but without specific consideration of combat damaged aircraft and BDR. The Navy has developed and uses the Comprehensive Aircraft Support Effectiveness Evaluation (CASEE) model for logistics analyses at Level III. Currently, CASEE is restricted to peacetime repairs and attrition (accidents).

Level IV Analysis

Level IV, or Force, analyses are large scale models, simulations, or simulators often referred to as *Wargames*, used to evaluate force effectiveness or to train theater commanders in warfighting doctrine and utilization of combat assets. Examples of Level IV analysis tools are:

- THUNDER, an air combat campaign model used by the Air Force
- JANUS, a wargaming model developed by, and resident at, Lawrence Livermore National Laboratory.
- The Army "Battle Labs", network of simulations and simulators planned for wargaming, exercise simulations, and training.

BDR capabilities (or lack thereof) for each weapon system *"played"* in the *"game"* should be considered. This is the level at which the "force multiplication" payoff of effective BDR is realized in terms of combat sustainment. Coordination should be initiated with Level IV analysts and methodology developers to incorporate "BDR effectiveness" parameters such as **return-to-combat rate** and **effective attrition** (see Level III definitions) into their models, simulations, or simulators.

Hierarchy Applications

Following are examples of how the hierarchy of analysis outlined in Figure 1. would be used in the system design, development, and acquisition process:

- Level I, Component, subsystem, and support equipment design analysis. Examples of how this level of analysis would be used include:
  - Engineering & Manufacturing Development Phase - for component design for ease of repair, interchangeability, and/or multi-functional use, materials selection for repairability, special equipment design and evaluation
  - Production and Deployment Phase - for personnel and spares planning, war reserves planning, training requirements, and BDR requirements verification.
- Level II, System design and logistics support analysis. Examples of how this level of analysis would be used include:

- Demonstration & Validation Phase - for design trade studies, combat supportability, and risk reduction analysis

- Engineering & Manufacturing Development Phase - for detailed BDR timeline analysis, serviceability/damage deferability analysis, and test evaluations.

- Level III, Field/base operations or system effectiveness analysis. Examples of how this level would be used include:

  - Concept Definition Phase - for use studies, system trade studies, and risk analysis

  - Cost and operational effectiveness analyses (COEA) of the system. Various system concepts would be analyzed and compared for complexity (special skills, equipment, spares requirements, ease of remove & replace, modularity/interchangeability of major assemblies, etc.) of BDR, repair time versus expected individual threat damage, and repair technique development requirements.

- Level IV, Force level or theater operations analysis. Examples of how this level of analysis would be used include:

  - Pre-Milestone 0 - for system requirements definition, logistics support concepts and requirements definition

  - Production and Deployment Phase - for manpower/personnel/training plans, spares planning, operations & maintenance budgeting.

  - Return-to-combat rate versus scenario types would be a typical parameter for quantifying BDR for this level of analysis.

  - Effective attrition would be the negative impact parameter for not providing adequate BDR capabilities.

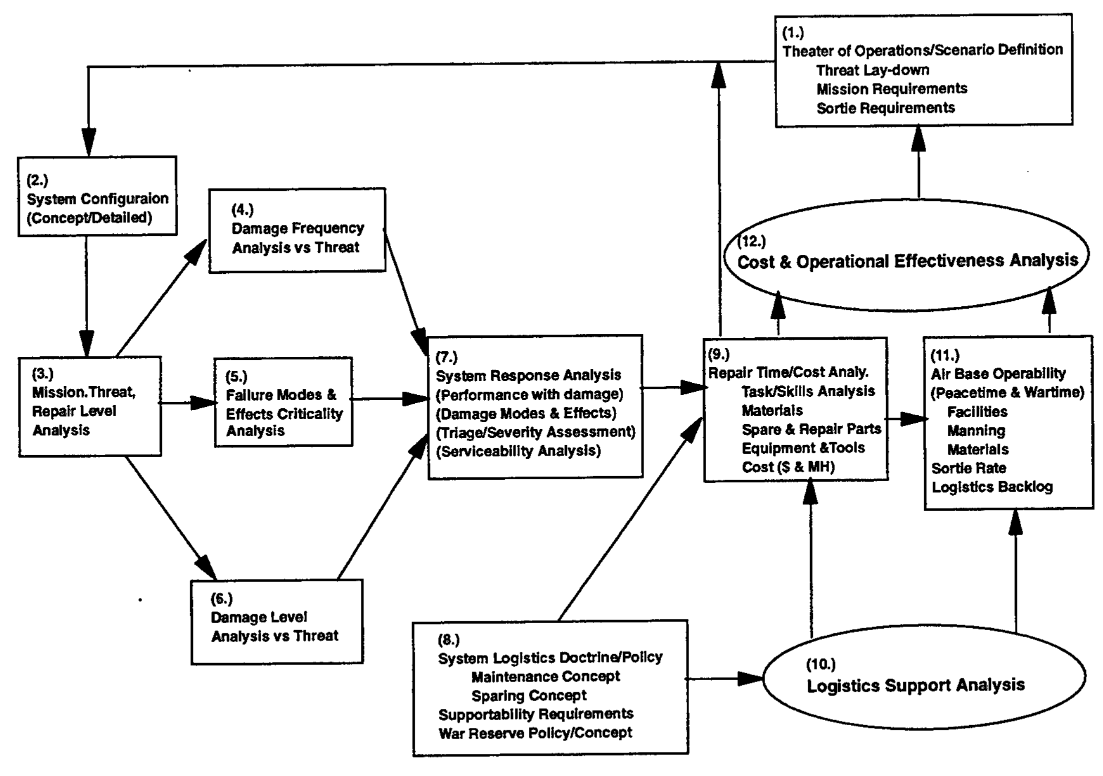
2.3 BDR Analysis Task Flow

A conceptual task flow diagram, Figure 2.2, is proposed as a means of visualizing the required elements of a BDR analysis.

Figure 2.2 can be used as a checklist for tracking progress in developing a DoD accepted aircraft BDR analysis methodology. A description of the information or data to be generated for each task can be developed. The procedures for generating the required information (computing environment, analysis methods, computer models, etc.), or other program documentation (mission need statement, operational requirement, system specification, system threat assessment report, etc.) which provides the required information can then be defined. This generic approach can be applied for all the Levels of Analysis discussed above.

Some of the key BDR analysis tasks listed in Figure 2. 2 can be linked to counterpart tasks in the COEA, survivability analysis, and LSA disciplines. BDR analyses should start with the same operational scenario (Block 1.), system configuration (Block 2.), and mission threat analysis (Block 3.) as the COEAs, survivability analyses, and LSAs.

Figure 2.2 Aircraft BDR Analysis Task Flow (Conceptual)



Blocks 4., 6., and 7. of the BDR analysis process require inputs from survivability analyses and should be compatible with the modeling environment used for survivabiliy. Block 4. is the primary point of BDR analysis interface with the susceptibility analyses done for survivability. This is also the interface point for modeling environment (DIME or J-MASS) compatibility. Block 6. is concerned with predicting the level of damage sustained when an aircraft is hit by various threats and is, therefore, directly related to the probability of component damage given a hit on the component ($P_{d/h}$), probability of component damage given a hit on the aircraft ($P_{d/H}$), probability of component kill given a hit on the component ($P_{k/h}$,), and/or probability of component kill given a hit on the aircraft ($P_{k/H}$) data from vulnerability analyses. Block 7. interface with survivability analyses is the point at which the disposition of the damaged aircraft is made. Killed versus repairable aircraft are identified, and initial repair queue determinations are made.

Blocks 5., 8., and 9., of the BDR analysis are closely related to the Integrated Logistics Support process and the LSA. Under Block 5., the failure modes and effects criticality analyses (FMECAs) done for reliability, maintainability, and survivability analyses in accordance with MIL-STD-1629, Procedures for Performing a Failure Modes and Effects Analysis, should be used for input to Block 7. Interface with LSA in Block 8. is required to ensure support concept compatibility with BDR analyses. Block 9. is the key point of BDR commonality with maintainability analyses where manpower, materials, spares, and equipment need to be consistent.

Blocks 9., 10., and 11. of the BDR analysis are the common link of BDR and LSA to the COEA process. BDR parameters or system characteristics produced within Blocks 9. and 10. need to have visibility within the COEA so that identifiable contributions of BDR to overall system cost effectiveness can be evaluated as part of the COEA.

2.4 BDR Database Considerations

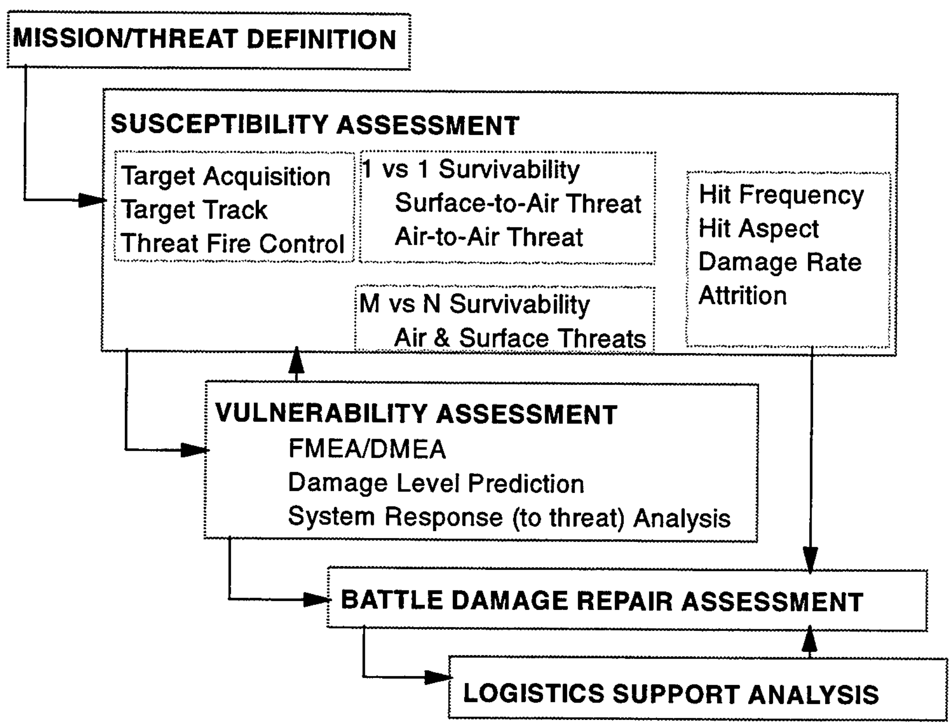
Several kinds of information and data are required as input to aircraft BDR analyses depending on the level of analysis, required fidelity, and/or time constraints for results. Sources of information and data may include other analyses, tests, military training exercises, and/or actual combat. In turn, BDR data is, or should be, input to higher level analyses to evaluate the payoff for enhanced BDR capability. Data requirements (parameters, level of detail, format, etc.) for BDR analysis should be coordinated with these sources and users as the BDR methodology is developed. The Level of Analysis also affects the required detail for input data. A detailed discussion of the kinds, sources, and uses of BDR data, along with a coordination checklist, can be found in APPENDIX C.

Chapter 3. Survey of Government and Industry BDR Analysis Methods

An extensive survey and interview process was conducted as follow-up to the aircraft BDR analysis methodology workshop. Government and industry engineers and analysts involved in BDR and the related survivability and logistics support disciplines were interviewed to identify analysis methods and models currently used to do BDR analysis. The survey questionaire and a list of survey participants can be found in APPENDIX D.

The BDR assessment process most commonly used, if a system BDR program exists, is shown in Figure 3.1.

Figure 3.1 The BDR Assessment Process (Current Approach)



The process outlined in Figure 3.1 requires a rather detailed point design of the system , at least as currently implemented. This process is most useful in the Engineering and Manufacturing Development (EMD) phase, or beyond, where the objective of the

BDR program is to develop BDR manuals, technical orders (TOs), or spares requirements. Repair manual or BDR TO development has been historically the focus of most system BDR programs. A serious shortcoming of this process is that it does not accommodate the up-front BDR assessment necessary to influence system design and logistics concept development. Two changes are required to appropriately consider BDR in the system acquisition process:

- First, logistics support engineers, BDR design engineers, and BDR analysts must become involved in the acquisition process at least as early as Concept Exploration and Definition Phase, and preferably during Pre-milestone 0 studies. Decisions made during these phases can be critical to the BDR capability that is eventually fielded. For example, one obvious, but crucial, decision which is made very early in the acquisition process is whether or not the concept calls for a throw-away, one time use, system. Many other less obvious decisions are made during these acquisition phases which affect downstream design and operational support for BDR.

- Second, BDR analysis methodology development must include relative measures of merit for BDR as extensions to survivability analysis and logistics support analysis (LSA) methods. The requirement is to be able to evaluate and rank various design and support alternatives on a relative basis. This capability is essential if explicit consideration of BDR is to be implemented in design trade studies in a practical manner. The survivability analysis community generally recognizes the relative nature of their results in evaluating alternatives. On the other hand, the LSA community generally orients analysis results to absolute terms (e.g., number of spares for provisioning, number of personnel with specific skill codes to man a base, technical order writing, time allocations for maintenance tasks, etc.). In general, their analysis methods have been developed for application much later in the acquisition cycle, after a final design has been established. BDR analysis must eventually address a final design configuration in order to develop technical manuals and specific manpower, materials, and spares requirements. However, quick response trade study methods are required for early system acquisition phases.

3.1 Current Capabilities

We encountered a great number of models, simulations, and computing environments during the interview and visit process. APPENDIX E contains descriptive information on these items.

It should be remembered that, up to now, aircraft BDR analyses, if done at all, have been done after system design is frozen. BDR analysis has typically been done during Engineering and Manufacturing Development (EMD) phase or later. The current capabilities discussed below reflect this situation. Also keep in mind the fact that this situation needs to be corrected.

Current methods for aircraft BDR analysis generally include the following :

- Geometric descriptions of the aircraft which use either 3-D computerized modeling or 2-D engineering drawings:

- Services use digitized models such as FASTGEN or a solid modeling environment such as BRL/CAD, developed by the Army Research Laboratory, Aberdeen Proving Ground, MD.

- Industry would prefer to use their in-house CAD/CAM program for geometric descriptions for vulnerability and BDR analyses. This would allow them to use the same system for geometric descriptions, engineering design (e.g., finite element analyses), and numerical control manufacturing methods.

- Damage prediction:

  - Some version of COVART is usually used for damage prediction for warhead single fragments and non-exploding projectiles. This is somewhat a misnomer since the current version of COVART is really just a bookkeeping tool. Damage, to the extent that it is "predicted" or defined, is actually described by COVART inputs in terms of damage or kill probability functions. COVART and its multiple fragment HEI derivative methods (see next bulleted item) calculate, or estimate, the projectile or fragment impact mass and velocity on a component and compare those impact parameters to pre-established criteria that define the residual capability for the component to perform its designated function. These criteria are called component $P_{d/h}$ (probability of damage given a hit) or $P_{k/h}$ (probability of kill given a hit) functions, curves, or tables.

  - For exploding projectiles, damage prediction can be done using one of several methods to convert from parallel shotlines to radial ray tracing for simulation of fragment spray. Computer codes such as HEIVAM, HEVART, or a modification of COVART do this conversion and track component damage using the damage or kill probability functions. Manual examination of drawings using damage area templates is often done to assess exploding projectile damage.

- Repair analysis:

  - For structural repairs, the analysis is generally done by experts with familiarity with structural design and field operations. These analysts take the damage predictions and estimate requirements (time, materials, tools, and personnel) to do the repairs.

  - For remove and replace items, logistics support analysis record (LSAR) standard times (from time line analysis) are generally used.

3.2 Methods in Development

There are some ongoing methodology developments which could eventually provide the capability to address aircraft BDR. These include:

- The degraded states vulnerability methodology being developed under the Target Interaction Lethality and Vulnerability (TILV) sub-sub-group by the Army Research Laboratory (ARL) is reported to have BDR applicability.

- The JTCG/ME, JTCG/AS, and the Army Research Laboratories (ARL) are initiating development of a model for evaluating lethality and effectiveness of all types of conventional anti-air munitions. This model, known as Advanced Joint Effectiveness Model (AJEM) is also reported to have BDR applicability. The JTCG/ME, JTCG/AS, and TILV are coordinating on AJEM requirements and supporting its development.

These efforts are attempting to start with first principles and physics to address damage prediction rather than the empirical basis of previous methods. Degraded states vulnerability methodology and AJEM should be tracked and an emphasis should be placed on coordinating BDR analysis requirements into their development.

3.3 BDR Analysis Methodology Needs/Shortcomings (from interviews)

All persons interviewed, even those who have performed aircraft BDR analyses (as distinguished from those who have performed subjective assessments for BDR) had concerns about the adequacy and validity of the data they used, problems with target modeling, and recommendations/suggestions for improving the process. The following items should be addressed as BDR analysis methodology is developed:

- Damage "prediction" shortcomings:
  - Frequency of damage should be an output of susceptibility analyses.
  - Identification of what gets damaged (including necessary level of detail) needs to be defined. "You need to know how many times you need to fix the "whatever" in a battle or operation."
  - Data bases for damage are largely look- up tables (often extrapolated) and very incomplete. Validity is also questioned.
  - Incorporate calculations rather than look-up tables.
  - Damage size calculation needs more robust metrics than A_V.
  - Damage mechanism modeling is key to "degraded states" approach and is currently limited to component being "on" or "off".
  - Programs for penetration equation development should also gather data for damage. Test programs for penetration equation development could also provide damaged test panels for repair technique development, particularly on exotic materials.
  - Classically, from a given aspect, hit distribution is random. Hit aspect may then be the primary bias to analyze.
  - Parts with "graceful degradation" are not handled in LSA.

- Low energy laser (LEL) and high power microwave (HPM) damage mechanisms are generally considered to be "soft kills" (i.e., they generally do not result in catastrophic damage or even damage observable by the naked eye in many cases) but may be important from a BDR or "effective attrition" standpoint.

- Target modeling:

  - Sensitivity analyses need to be done to determine required level of detail for target descriptions and databases.

  - Component "grouping" in target descriptions needs to be coordinated for vulnerability and BDR analyses.

  - FASTGEN and COVART codes need a numbering system compatible with other system disciplines. At this point it is impossible to track components modeled for FASTGEN and COVART through the procurement process. Names and numbers are assigned by vulnerability without regard for future needs for matching their results to future procurement of parts and assemblies. Two recommendations are offered to correct this problem.

    - Recode FASTGEN and COVART to accept different component naming and numbering schemes. Discussions with the Air Force Aeronautical Systems Center (AF/ASC) indicate that not much effort would be required to recode the models to use standard part numbers [e.g., the contractor's assigned part number (P/N), National Stock Number (NSN), or Logistics Control Number (LCN)]. The logistics control number (LCN) seems to be the most appropriate means of tracking components through development.

    - Develop a cross reference matrix during system development. Another suggestion was to develop a matrix to cross reference various component and part numbering schemes used during system development. This would add another documentation requirement to system acquisition, but may be a more practical approach for systems that already have target descriptions.

  - 2 inch grid size for shotline evaluation seems to be standard. Grid size evaluation should be part of the sensitivity analyses conducted to ascertain proper level of detail.

  - A target description catalog would be useful (SURVIAC is working on one, and the Army has their own.). Information should include:

    - Intended purpose

    - Level of detail

- Number of components described (list of components would be useful)
- Compatibility with various analysis models

- Repair data:
  - Repair data generation is "input intensive" and databases have not been generated for repair of front line aircraft.
  - The Delphi method has been used to develop repair data bases using senior technicians as the expert estimators. This method may be appropriate for evaluating preliminary concepts and designs if assumptions and references forming the basis of estimates are documented and limitations are identified.

- Platform analysis:
  - Need to identify areas "most likely" to be damaged and "high payoff" repair technique developments.
  - Do a "cell" or compartment by compartment analysis of the aircraft to identify "hot spots" or critical areas for BDR technique developments.
  - Missile modeling (ESAMS) can be used to get orientation and burst points for fragment spray.
  - System analyses need to address "characteristics" (acceleration, speed, maneuverability, fire rate, etc.) rather than "parameters". (This comment is from the discussions on the degraded states analysis concept.)

- Higher level analyses:
  - Unrealistic and/or rigged attrition analyses (e.g., managed attrition) have been used often to assess damage rates versus attrition.
  - Measures of Effectiveness (MOEs) or Figures of Merit (FOMs) such as sortie generation, sorties completed, and number of aircraft damaged but unavailable due to needed repairs or unavailable spares have been suggested.
  - Measures of Outcome (MOOs), MOEs, and Measures of Performance (MOPS) for BDR needed to fit with the Digital Integrated Modeling Environment (DIME) and possibly eventually with the Joint Modeling and Simulation System (J-MASS).
  - BDR should be integrated with the Survivability Requirements and Assessment Manual (SURVRAM), a JTCG/AS Methodology Subgroup undertaking, since BDR analysis is part of the system assessment process that also encompasses survivability.

- **The Government must provide the "Operational Context" (complete scenario) to do the analysis.** Interviewees from industry stressed this as a problem for system effectiveness analyses across the board, not just for BDR.

- Field analysis aids:

  - Interactive, automated visual presentations of the aircraft would be useful (e.g., BRL/CAD "pictures") to give technicians graphical displays of aircraft internal arrangement.

  - A simple "stress analysis calculator" is needed for field use in design of repairs.

- BDR related parameters/system characteristics need to be defined which can be calculated using logical extensions of survivability or logistics support methodologies. Potential BDR "parameters" include:

  - Damage rate - Rate at which aircraft receive survivable damage

  - $MaxTTR_{SD}$ - Maximum time to repair survivable damage

  - $P_{REPAIR\ in\ X\ hrs}$ - Probability of repair in X hours

  - Repair life (e.g., 100 flight hours)

  - Return-to-combat rate (RTCR) - Rate at which damaged aircraft are returned to the battle

  - Sortie generation rate (with and without BDR capability)

  - Effective attrition rate - Rate at which damaged but surviving aircraft are lost to the battle

  - Number of aircraft down (in the queue) due to battle damage - Maintenance aand/or logistics back-log

- General comments during interviews and visits:

  - Language and semantics differences as well as misunderstood concepts of analytical results between aircraft designers, survivability analysts, and LSA analysts **must** be addressed and bridged! ***Relative*** analysis results are generally used to perform design trade studies and for survivability analysis. For example, given several design options, which is best from an aircraft survivability standpoint when encountering a specified threat? ***Absolute*** analysis results are currently required for the details of logistics support analysis. For example, given an aircraft design, how many times will a specific part be damaged and need maintenance or replacement per 100 hours of exposure to a specified threat?

- Validation is needed for both models <u>and</u> input data. Analytical results are as much dependent on input data as they are on mathematical modeling, particularly since some models (e.g., COVART for vulnerability analysis) are primarily bookkeeping for various input parameters.

Chapter 4. Recommendations

Two types of recommendations are made for continuing the development of DoD accepted BDR analysis methodology. The following two general recommendations are made to establish terms of reference through which analysts from differing disciplines can discuss the BDR analysis process:

- Establish a hierarchy of BDR analysis to guide the level of detail required for specific analyses. Figure 2.1 is a suggested hierarchy.
- Define a BDR analysis process which specifies BDR analysis tasks and the analytical interfaces with survivability and LSA procedures. Figure 2.2 is offered as a suggested BDR analysis process concept.

In addition, there are four recommendations to implement actions that will lead to establishment of analysis techniques or models for doing BDR analyses. These recommendations are expanded in the following sections as a BDR analysis methodology development roadmap and specific tasks to implement the roadmap.

- Integrate BDR analysis as an extension of DoD accepted survivability analysis methods for damage prediction and as an extension of DoD accepted logistics support analysis (LSA) methods for repair analysis.
- In the near term, develop BDR analysis methodology based on FASTGEN and COVART, the most commonly used damage prediction models, and on extensions to LSA methods for repair time and resources analysis.
- Establish longer range BDR analysis methodology development tasks based on in-development or proposed damage prediction methods and LSA repair analysis methods.
- Coordinate BDR model development with the establishment of DoD accepted modeling and simulation environment(s) (e.g., Digital Integrated Modeling Environment or Joint Modeling and Simulation System) in the same manner that JTCG/AS Survivability Methodology Subgroup models are envisioned to be handled.

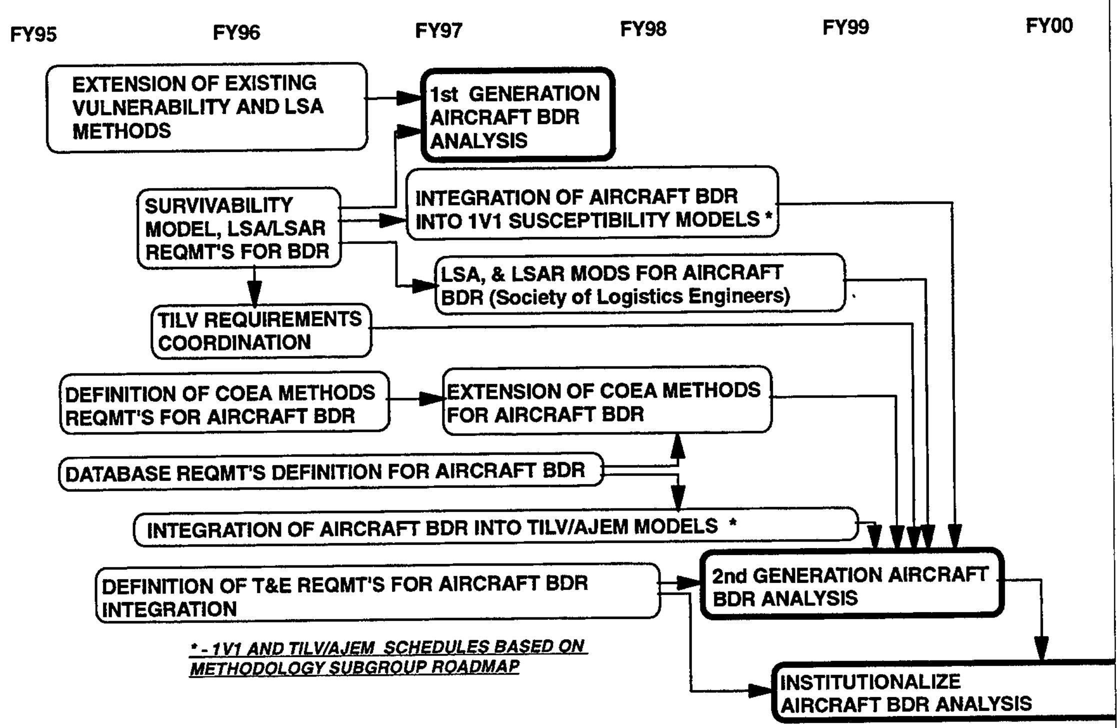
4.1 Roadmap for Aircraft BDR Analysis Methodology Development

The recommended approach for aircraft BDR analysis methodology development is to adopt a planning roadmap and establish specific projects that meet near-, mid-, and long-term goals for institutionalizing the aircraft BDR analysis process. Near-term goals are those which should be accomplished in the next one to two years. Mid-term goals are those that need two to four years to accomplish. Long-term goals are those which are projected for four years and beyond.

Figure 4.1 is a recommended roadmap for establishing and implementing a DoD accepted BDR analysis methodology. The endpoint of the roadmap is the institutionalization of aircraft BDR analysis as an integral part of the system engineering analysis

process. However, there are intermediate objectives that will allow reasonable quantification of BDR capabilities and relative ranking of system design and support alternatives to perform trade studies for aircraft BDR.

Figure 4.1 Aircraft BDR Analysis Methodology Development Roadmap



The 1st generation BDR analysis capability builds on existing survivability and logistics support analysis methods. Based on the findings in this report, recommended JTCG/AS work statements will be drafted to do the near-term tasks for the 1st generation capability.

The 2nd generation capability will be based on further extending ongoing survivability model developments and identifying requirements in the logistics support analysis/logistics support analysis record (LSA/LSAR) and the cost and operational effectiveness analysis (COEA) methodologies to address BDR. As noted in Figure 4.1, scheduling for the one versus one susceptibility analysis capability and the TILV/AJEM vulnerability analysis capability is predicated on the JTCG/AS Methodology Subgroup Roadmap.

4.2 BDR Analysis Methodology Development Tasks

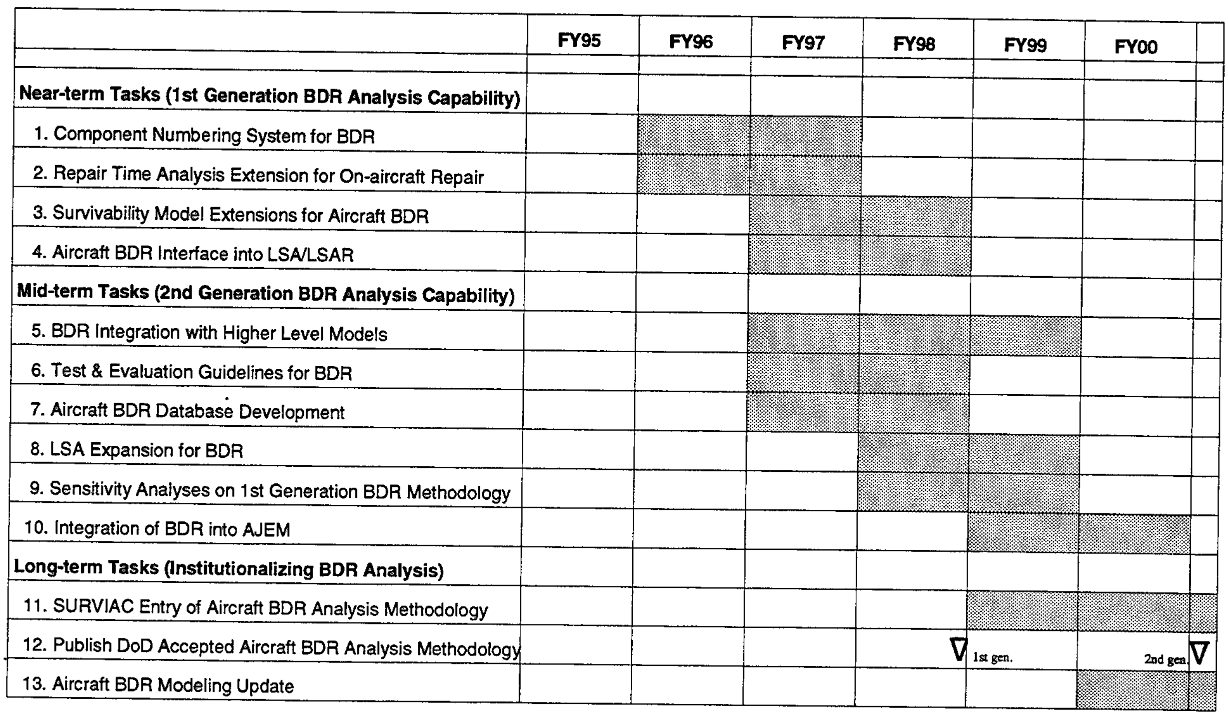
Near-, mid-, and long term tasks have been identified to meet the above listed goals for BDR analysis methodology development. Figure 4.2 lists the recommended tasks to accomplish the aircraft BDR analysis methodology development roadmap. Near-, mid-,

and long-term tasks are identified which will build first and second generation capabilities leading to eventual institutionalization of aircraft BDR analysis.

This phased approach is recommended, because critical decisions are being made on future aircraft systems without the benefit of quantitative trade studies on BDR. A reasonable capability is urgently needed. The near-term tasks are structured to provide this 1^{st} generation capability.

The 2^{nd} generation capability is structured to be developed concurrently with, or as an integral part of, the ongoing JTCG/AS Methodology Subgroup program; hence, the roadmap tie to susceptibility and vulnerability modeling milestones. The LSA/LSAR interface was initiated at the first aircraft BDR analysis methodology workshop, but will have to be revitalized for this effort.

Figure 4.2 - Task Schedule for Aircraft BDR Analysis Methodology Development



The eventual institutionalization of BDR analysis will depend upon formalizing analytical methods, establishing appropriate databases, and publishing educational materials of various kinds to promulgate the discipline. The institutionalization process will be a continuing effort to maintain state-of-the-art capabilities as is every analysis discipline.

Near-term Tasks -

The objective of near-term aircraft BDR analysis methodology development tasks is to supplement existing models, codes, and/or analysis methods to account for BDR

specific parameters in a reasonable manner. Accomplishment of near-term tasks is intended to result in the 1st generation aircraft BDR analysis capability. Convening of one or more workshops to coordinate task progress is anticipated. (Task numbers refer to the Figure 4.2 task numbering system.)

Task 1. - Component Numbering System for BDR:

Determine the most appropriate part, component, assembly, LRU, and/or LRM numbering and naming system so that components and assemblies identified by the vulnerability analysis as damaged or killed can be tracked through the procurement system. At least two alternatives should be investigated. The first alternative is to recode target description and vulnerability analysis models to accept standard, logistics-related part numbering and naming methods. The Logistics Control Number (LCN) has been suggested by the Army for this purpose and seems to have support from the Air Force. A second alternative is to develop a part number cross-referencing matrix that allows interpretation of various numbering systems. Pros and cons of these, or other alternatives, need to be identified and discussed.

Task 2. - Repair Time Analysis Extension for On-aircraft Repair:

Develop an approach and update or modify the repair time (RT) module of COVART to more realistically address repair options and repair time analyses. The current configuration of COVART uses look-up tables of component repair times and either sums damaged component remove and replace times or picks the longest component remove and replace time depending on whether sequential or simultaneous repairs are done. As configured, COVART picks one value for repair time for each component based on projectile velocity and mass. Realistically, several other options may be available to the BDR engineers and technicians. Remove and replace, repair in place, bypass, or defer repair are possible options. System BDR evaluations need to have flexibility for considering these options when comparing and ranking design alternatives.

Damage severity, mission requirements, system and/or component design, and available resources (skills, equipment, and materials) can significantly affect which BDR option would be better. This task is to identify alternatives for updating current BDR analysis methods to accommodate more realistic situations. One alternative would be to investigate the possibility of incorporating timeline analysis used by maintainability engineers for maintenance man-hour predictions into the COVART program. This approach would also provide compatible output for integrating BDR into the reliability, availability, maintainability (RAM) analysis process.

This task should also address database requirements of 1st generation aircraft BDR analysis methodology. Recognizing that 1st generation methods will be based on existing survivability and LSA methods, database requirements identification and collection of available data should be done along with methodology extensions.

Task 3. - Susceptibility Model Extensions for Aircraft BDR:

Add output options to existing susceptibility models to provide "expected" attack and/or hit directions, hit density, and hit distribution by viewing aspect. The intent is to

provide an indication of the most prevalent hit directions as guidance to BDR analysts and engineers for scoping the extent of their detailed BDR analyses. This data is useful also to vulnerability analysts and engineers to identify areas of most concern. BDR engineers are interested in parameters related to survivable damage (i.e., areas that will need to be repaired before the next mission). Vulnerability engineers, on the other hand, are interested in identifying areas that result in loss of the airplane (i.e., areas that need vulnerability reduction techniques applied).

Susceptibility models that should be addressed include RADGUNS, ESAMs, and TAC Brawler or AASPEM/MIL AASPEM. The task includes review of the models, evaluation of their current capability to provide the required data, and revising the models either by adding output options or modifying code, if necessary, to provide BDR analysis input data.

Task 4. - Aircraft BDR Analysis Interface with Logistics Support Analysis (LSA)/Logistics Support Analysis Record (LSAR):

Develop a procedure to accommodate **relative** results from survivability analyses into the LSA process. Resolve the apparent issue of **"absolute"** versus **"relative"** analysis results requirements between the logistics support and the survivability analysis communities. The survivability community has been working toward acceptance of "relative measures of performance" to evaluate design alternatives in trade studies. Some of these methods can be extended rather easily to provide relative measures of damage frequency, hit aspect, and damage severity for aircraft BDR analyses.

Logistics oriented characteristics of BDR (e.g., manpower/skills, time to repair, initial provisioning, spares, etc.) based on relative goodness measures of merit rather than absolute values need to be developed. The problem seems to be that the LSA methods are "demand based" models that rely on databases developed through operational usage so that "absolute" values can be predicted for future utilization rates. Thus, when logistics support analysts are asked to apply their methods to BDR, they request absolute values. For example, "How many times will '*xyz*' component be damaged in 100 flight hours of operation?" or "What is the precise size of the damage to '*xyz*' component?" In order to perform system design trade studies for BDR with reasonable economy of analytical resources (time, manpower, and computer resources), the relative ranking of design and support concepts for BDR needs to be determined.

Mid-term Tasks -

The overall objective of mid-term tasks is to ensure logical evolution of a 2nd generation aircraft BDR analysis capability. Two key elements for attaining this objective are:

- Extension of BDR considerations into higher level analyses (e.g., mission level and COEAs)

- Integration of aircraft BDR analysis considerations into selected ongoing survivability and LSA methodology developments. A number of ongoing modeling, simulation, and computing environment developments (see Chapter 3., par.. 3.2.) need to

be reviewed and formal coordination efforts instituted on selected efforts to integrate BDR analysis requirements.

The following tasks make up the recommended mid-term aircraft BDR analysis methodology development program:

Task 5. - BDR Integration into Higher Level Models:

Identify BDR related system level parameters and operational characteristics to integrate BDR into system cost and operational effectiveness analyses (COEAs). Coordinate with COEA developers and analysts to define appropriate measures of military worth for BDR capabilities as separate COEA inputs or extensions of current measures of outcome, measures of effectiveness, and/or measures of performance. Models that should be reviewed and evaluated for applicability include LCOM, TSAR, TSARINA, RQM, and SPARC. ROTA may also provide BDR related data for COEA input but is currently considered proprietary. These models are described in section 3.1.

Task 6. - Test and Evaluation (T&E) Guidelines for BDR:

Establish BDR interface requirements to maximize use of test resources in development, live fire, and operational T&E. As a minimum, survivability and maintainability testing procedures should be reviewed, and potential extensions identified to incorporate BDR considerations. Some survivability testing has incorporated specimen repair as part of the program. However, the primary purpose has been to extend specimen life. BDR data requirements have not been addressed in sufficient detail to provide useful documentation of results for follow-on analysis. This task is to formalize BDR integration into the overall T&E process.

Task 7. - Aircraft BDR Database Development:

Acquire and review aircraft BDR data and database programs from all the Services. Establish a DoD aircraft BDR database program and initiate database population. Examples of data to be considered include data required for:

- Test versus analytical comparison
- Damage level prediction by threat
- Selection of repair techniques
- Materials, equipment, and technician skills for field level repairs
- System design for BDR
- BDR design

Task 8. - Logistics Support Analysis Expansion for BDR:

Identify and document updates to MIL-STD-1388-1 and -2 to more fully address BDR. Review the logistics support analysis (LSA) tasks in 1388-1 and recommend appropriate extensions for BDR. Each task, from strategy development (Task 101) through supportability test, evaluation, and verification (Task 501), has BDR implications that need to be addressed. Additionally, the logistics support analysis records and associated reports in 1388-2, require updating to adequately address BDR analysis requirements. The LSAR currently provides for failure mode and effects and damage mode and effects analysis for survivability and vulnerability assessments and for criticality and maintainability analyses. These should form the basis for extension to BDR.

Task 9. - Sensitivity Analyses on 1st Generation BDR Methodology:

Define appropriate test cases and , using the near-term 1st generation BDR analysis methodology, perform sensitivity analyses to establish recommended levels of detail for potentially costly data development. For example, building excessively detailed geometric descriptions and/or damage prediction models must be avoided. They would most likely be too costly in computer resources (hardware, software, and run time) and manpower for practical application to system acquisition analyses. A balance is needed for realism, reasonableness, and affordability in BDR analysis. This task should feed recommendations and criteria into 2nd generation capability.

Task 10. - Integration of BDR into Advanced Joint Effectiveness Model (AJEM):

AJEM is being developed jointly by the JTCG/AS, JTCG/ME, and JDL sub-sub-panel on TILV as the next generation aircraft vulnerability analysis model. The objective of this task is to ensure that aircraft BDR analysis requirements are identified and integrated into AJEM. Lessons learned during 1st generation BDR methodology development and the sensitivity analyses should be input to AJEM development.

Long-term Tasks -

Long-term aircraft BDR analysis methodology tasks are intended to ensure maturation and sustainment of BDR analysis as an integral part of the systems engineering analysis discipline.

Task 11. - SURVIAC Entry of Aircraft BDR Analysis Methodology:

Combine 1st and 2nd generation aircraft BDR analysis methodology developments into form for entry into SURVIAC. This task must be coordinated with the associated model developments, including verification and validation, database development, and modeling environment integration requirements (e.g., cradling model development for DIME and/or J-MASS).

Task 12. - Publish a DoD Accepted Aircraft BDR Analysis Methodology:

Document a detailed approach for conducting DoD acceptable aircraft BDR analyses. The output of this task will be consolidation of the results of the near-term and mid-

term efforts and publication of an aircraft BDR analysis handbook. This handbook should a complete discussion of the aircraft BDR analysis process, its interface with other system engineering disciplines, methodology/model descriptions, sample analyses, database descriptions, and resource references for further information.

Task 13. - Aircraft BDR Modeling Update:

Perform aircraft BDR analysis model updates as shortcomings are identified, technology (both hardware and software) advances, databases expand, and battlefield simulation as a training device or as an actual weapon system is implemented. This task is a continuing effort to maintain BDR analysis as an institutionalized discipline.

The above listed tasks will be expanded into the format of JTCG/AS statements of work as a follow-on effort of the OSD directed JTCG/AS aircraft BDR initiative.

APPENDIX A. - List of Acronyms

Acronym	Meaning
AASPEM	Air-to-air system performance model
ACES/Phoenix	Adaptive combat environment system with Phoenix graphical user interface
AF/ASC	Air Force Aeronautical Systems Center
AJEM	Advanced joint effectiveness model
ALARM	Advanced low altitude radar model
AMSAA	Army Materiel Systems Analysis Activity
ARL	Army Research Laboratory
A_V	Vulnerable area of the aircraft
A_v	Vulnerable area of a component
BDR	Battle damage repair
BRL/CAD	Ballistics Research Laboratories/Computer aided design
CASEE	Comprehensive aircraft support effectiveness evaluation
CATIA	Computer aided design and manufacturing software package developed by Dassault Aviation
COEA	Cost and operational effectiveness analysis
COVART	Computation of vulnerable areas and repair time
DIME	Digital integrated modeling environment
DMEA	Damage modes and effects analysis
DoD	Department of Defense
EMD	Engineering and manufacturing development
ESAMS	Enhanced surface-to-air missile simulation

FASTGEN	Fast shotline generator
FMECA	Failure modes and effects criticality analysis
FOM	Figure of merit
GSE	Ground support equipment
HEIVAM	High explosive incendiary vulnerable area model
HELIPAC	Helicopter piloted air combat
HEVART	High explosive vulnerable area and repair time
HPM	High power microwave
IMARS	Integrated missile and radar simulation
J-MASS	Joint modeling and simulation system
JSEM	Joint Service endgame model
JTCG/AS	Joint Technical Coordinating Group on Aircraft Survivability
JTCG/ME	Joint Technical Coordinating Group for Munitions Effectiveness
LCN	Logistics control number
LCOM	Logistics composite model
LEL	Low energy laser
LELAWS	Low energy laser weapon simulation
LMI	Logistics Management Institute
LRM	Line replaceable module
LRU	Line replaceable unit
LSA	Logistics Support Analysis
LSAR	Logistics support analysis record
MAVEN	Modular aircraft vulnerability estimating module
$MaxTTR_{SD}$	Maximum time to repair survivable damage

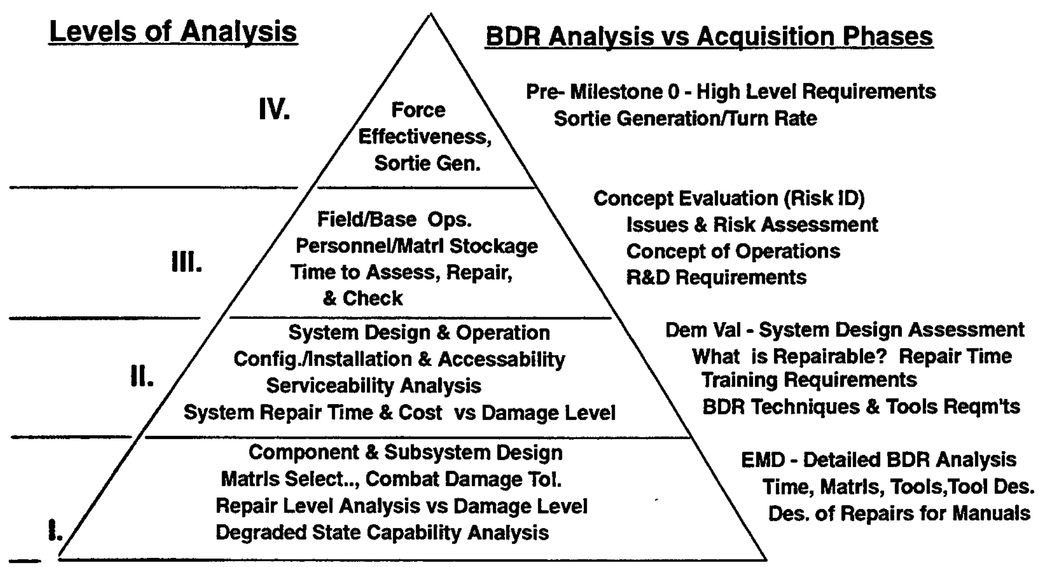
MEL	Maintenance expenditure limit
MGED	Multi-device graphics editor
MIL AASPEM	Man-in-the loop AASPEM
MOE	Measure of effectiveness
MOO	Measure of outcome
MOP	Measure of performance
MPT	Manpower, personnel, and training
MUVES	Modular UNIX-based vulnerability estimation suite
NSN	National stock number
OSD	Office of the Secretary of Defense
$P_{d/H}$	Probability of component damage given a hit on the aircraft
$P_{d/h}$	Probability of component damage given a hit on the component
$P_{k/H}$	Probability of component kill given a hit on the aircraft
$P_{k/h}$	Probability of component kill given a hit on the component
P/N	Part number
$P_{REPAIR\ in\ X\ hrs}$	Probability of repair in X hours
RADGUNS	Radar-directed gun system simulation
RAM	Reliability, availability, and maintainability
ROTA	Return-to-combat of tactical aircraft
RQM	Resource quantification model
RTCR	Return-to-combat rate
SCAN	Survivability computerized analysis
SHAZAM	Point burst vulnerability analysis model
SPARC	Sustainability predictions for Army spare component requirements

SQuASH	Stochastic quantitative analysis of system hierarchies
SURVIAC	Survivability and Vulnerability Information Analysis Center
SURVRAM	Survivability requirements and assessment manual
TILV	Target interaction lethality and vulnerability
TMAS	Tactical mission analysis system
TMDE	Test, measurement, and diagnostics equipment
TO	Technical order
TRAP	Trajectory analysis program
TSAR	Theater simulation of airbase resources
TSARINA	TSAR input using airbase damage assessment

APPENDIX B. - Hierarchy of Battle Damage Repair Analysis

Figure B.1. outlines a conceptual hierarchy of battle damage repair (BDR) analysis for addressing the various levels of analytic detail needed to meet the requirements to address BDR capability quantification throughout the weapon system acquisition process. The 4 levels of detail for BDR analysis depicted in Figure B.1 are consistent with those generally accepted for most system engineering analysis disciplines including survivability.

Figure B.1 Hierarchy of Aircraft BDR Analysis



The level of physical detail needed to analyze BDR is the highest in Level I. As analyses proceed up the hierarchy, the physical detail is reduced and overall system characteristics are introduced. This hierarchy can be used also to allocate BDR requirements from the top down. As system design evolves, iterations should be made to assess the impact of various design details on the higher Level system BDR characteristics and to track compliance with the requirements.

Level I Analysis

Level I BDR analysis is conducted at the component level and addresses the inherent design characteristics of the component which affect repairability in the field. These characteristics include things such as material selection, component interchangeability, and markings for ease of identification. Although, the level of physical detail needed to analyze BDR is the highest in Level I, the decisions made at the component design level can greatly affect the overall system design for repairability. A Level I BDR analysis is analogous to survivable component design analysis (e.g., rip-stop or jam-resistant hydraulic actuators, multi-spar wings, toughened epoxy composite materials, etc.).

A Level I BDR analysis should take into account component design considerations such as:

- Materials selection (i.e., Is there an established field repair technique for the material, are there tools available to repair the material, or does it take special skill to repair the material?)
- Non-handed/interchangeable component design, size and weight of remove and replace components (i.e., Field personnel should be able to handle remove and replace components or be provided with easy to use tools to handle them.)
- Modular design for large components (e.g., engines, wings, fuselage, and empennage)
- Coded/marked/labeled components or assemblies (e.g., individual wires in a harness, fluid lines, and connectors)
- Fastener selection (e.g., Use a minimum number of different types and sizes, minimize or avoid special fasteners, and avoid time consuming fastener and connector designs such as lock-wired.)
- Component repair (on the aircraft) versus remove and replace

To a great extent, Level I BDR analyses might be considered good, common sense design analyses. However, if they are not explicitly conducted, poor BDR design can, and often does, result. Documentation of Level I analyses can also provide data for input to Level II analyses.

Level II Analysis

Level II BDR analysis deals with platform or vehicle design considerations to enhance BDR capabilities. It is comparable to survivability analyses that address a single operating aircraft as it encounters a single operating threat system. These are usually referred to as "platform" or "1 on 1" analyses. Level II is the lowest level at which overall vehicle design trade studies are made. Comparable Level II survivability analyses would be calculation of aircraft vulnerable area (A_V) versus a specific threat (e.g., COVART) or aircraft probability of kill (P_K) versus a specific threat (e.g., ESAMS).

A Level II BDR analysis should provide data to assess:

- Repair time versus threat for input to serviceability criteria for field level triage
- Repair time sensitivity to aircraft configuration for design trade studies
- BDR techniques and tool development requirements for input to technical manuals, BDR kit development, and R&D programs
- BDR task, timeline, and skills analysis for input to technical manual, training requirements, and logistics support requirements.

Level II analyses, because they are system or vehicle oriented, are typically those most often implied in discussions of BDR. In addition to addressing the system design and BDR technology application issues, multiple Level II analyses can generally be aggregated as input to Level III and/or IV analyses.

Several efforts to develop Level II BDR models were, or are being, undertaken with none being totally successful. These include COVART which is continually being developed by various organizations, the SCANMOD/REPAIR model development by the Air Force at Wright-Patterson AFB, OH, and the degraded states vulnerability methodology being developed by the Army Research Laboratory at Aberdeen Proving Ground, MD.

Level III Analysis

Level III BDR analyses are base level analyses that address issues related to BDR during combat operations on a base or carrier. Several types of aircraft would be flying various missions against an array of threats. Level III BDR analyses are comparable to survivability analyses that address multiple aircraft encountering multiple threats, ground based and/or airborne. In the survivability community, these are referred to as "few-on-few" or "M-on-N" analyses which are used to assess targets killed versus aircraft lost or exchange ratios. Examples of Level III aircraft survivability models are TAC Brawler, an Air Force developed model, and tactical mission analysis system (TMAS), used by Bell Helicopter/Textron. The Air Force has used a scenario based model, Logistics Composite Model (LCOM), to assess sortie generation rate from recovery to take-off, but without specific consideration of combat damaged aircraft and BDR. The Navy has developed and uses the Comprehensive Aircraft Support Effectiveness Evaluation (CASEE) model for logistics analyses at Level III. Currently, CASEE is restricted to peacetime repairs and attrition (accidents).

A Level III BDR analysis should address base or carrier operations parameters such as:

- Personnel requirements to support expected BDR activities, either as augmentees to routine maintenance or special training for maintenance technicians (BDR concept of operations)

- Tools, equipment, and materials prepositioned or readily available for shipment (airlift) to the base or carrier

- Return-to-Combat Rate (RTCR) of damaged aircraft as it affects sortie generation

- Effective attrition [i.e., Aircraft that sustain survivable damage but are lost to the commander because they cannot be repaired in the field for one reason or another (e.g., lack of spares, BDR technique, technician, available, etc.)]

- Logistics backlog at the base or carrier

Four models were identified which address at least some of the Level III BDR analysis issues. They are:

- The Resource Quantification Model (RQM), under development by the Air Force Armstrong Laboratory, addresses air operations and uses data from SCANMOD/REPAIR. Some difficulty has been encountered in getting this model running.

- The Sustainability Predictions for Army Spare Component Requirements for Combat (SPARC) model, developed by the Army Materiel Systems Analysis Activity (AMSAA), uses output from a theater N-day analysis and predicts spares requirements. Attempts to acquire details on SPARC, primarily a ground combat vehicle analysis tool, and aircraft BDR analysis methodology development recommendations from AMSAA were unsuccessful. However, SPARC does seem to be operational and may be an option for aircraft BDR analysis.

- Theater Simulation of Airbase Resources (TSAR), developed by RAND and a potentially useful model. Database generation for TSAR is manpower intensive at this point. TSAR has been used by the Air Force to evaluate airbase operations, including base enemy attack with both base and parked aircraft damage and with chemical weapon attack.

- Return-to Combat of Tactical Aircraft (ROTA), a proprietary (to Alpha Research Corp.) model developed by Alpha Research Corp., analyzes changes in capability to repair battle damage in terms of platform sortie generation and maintenance load. ROTA is a quick-look, higher level model that was used by LMI in their initial work to quantify potential payoff of various levels of enhanced BDR capability.

Level IV Analysis

Level IV, or Force, analyses are large scale models, simulations, or simulators often referred to as *Wargames*, used to evaluate force effectiveness or to train theater commanders in warfighting doctrine and utilization of combat assets. Examples of Level IV analysis tools are:

- THUNDER, an air combat campaign model used by the Air Force

- JANUS, a wargaming model developed by, and resident at, Lawrence Livermore National Laboratory.

- The Army "Battle Labs", network of simulations and simulators planned for wargaming, exercise simulations, and training.

BDR capabilities (or lack thereof) for each weapon system *"played"* in the *"game"* should be considered. This is the level at which the "force multiplication" payoff of effective BDR is realized in terms of combat sustainment. Coordination should be initiated with Level IV analysts and methodology developers to incorporate "BDR effectiveness" parameters such as **return-to-combat rate** and **effective attrition** (see Level III definitions) into their models, simulations, or simulators.

Hierarchy Applications

Following are examples of how the hierarchy of analysis outlined in Figure 1. would be used in the system design, development, and acquisition process:

- Level I, Component, subsystem, and support equipment design analysis. Examples of how this level of analysis would be used include:

  - Engineering & Manufacturing Development Phase - for component design for ease of repair, interchangeability, and/or multi-functional use, materials selection for repairability, special equipment design and evaluation

  - Production and Deployment Phase - for personnel and spares planning, war reserves planning, training requirements, and BDR requirements verification.

- Level II, System design and logistics support analysis. Examples of how this level of analysis would be used include:

  - Demonstration & Validation Phase - for design trade studies, combat supportability, and risk reduction analysis

  - Engineering & Manufacturing Development Phase - for detailed BDR timeline analysis, serviceability/damage deferability analysis, and test evaluations.

- Level III, Field/base operations or system effectiveness analysis. Examples of how this level would be used include:

  - Concept Definition Phase - for use studies, system trade studies, and risk analysis

  - Cost and operational effectiveness analyses (COEA) of the system. Various system concepts would be analyzed and compared for complexity (special skills, equipment, spares requirements, ease of remove & replace, modularity/interchangeability of major assemblies, etc.) of BDR, repair time

versus expected individual threat damage, and repair technique development requirements.

- Level IV, Force level or theater operations analysis. Examples of how this level of analysis would be used include:

  - Pre-Milestone 0 - for system requirements definition, logistics support concepts and requirements definition

  - Production and Deployment Phase - for manpower/personnel/training plans, spares planning, operations & maintenance budgeting.

  - Return-to-combat rate versus scenario types would be a typical parameter for quantifying BDR for this level of analysis.

  - Effective attrition would be the negative impact parameter for not providing adequate BDR capabilities.

APPENDIX C. - Battle Damage Repair Database Considerations

Several kinds of information and data are required as input to aircraft battle damage repair (BDR) analyses depending on the level of analysis, required fidelity, and/or time constraints for results. Sources of information and data may include other analyses, tests, military training exercises, and/or actual combat. In turn, BDR data is, or should be, input to higher level analyses to evaluate the payoff for enhanced BDR capability. Data requirements (parameters, level of detail, format, etc.) for BDR analysis should be coordinated with these sources and users as the BDR methodology is developed. The Level of Analysis also affects the required detail for input data.

A coordination checklist for kinds, sources, and uses of BDR data and information includes the following:

- Kinds of Data for BDR Analysis Input:
  - Threat encounter and hit frequency (i.e., How often are various threats encountered and how often is damage sustained?)
  - Damage location (i.e., Where on the aircraft is damage most likely and from which threats?)
  - Threat effects (i.e., level of damage sustained):
    - Penetration into the aircraft (i.e., How far into the aircraft does the threat effect extend?)
    - Hole size or "effective" hole size considering penetration, petalling, shattering, and/or delamination
    - Blast/overpressure effects (from high explosives, nuclear detonation, or laser exposure)
    - Thermal effects (from fire, explosion, nuclear detonation, or laser exposure)
    - Electromagnetic effects (e.g., electronic upset or burnout)
    - Chemical effects (e.g., corrosion, seal softening, or structural integrity degradation)
    - Radiation effects (neutron, electron, gamma ray, or X-ray exposure).
  - Damage assessment (i.e., damage severity or system response to threat effects):
    - Serviceability of damaged aircraft (i.e., Level of damage versus combat performance capability, degraded capability, operational limitations, etc.)

            - Triage or recommended disposition of damaged aircraft (e.g., defer repair and place on flying status - may carry limitations, repair queue priority, retain for parts bin or controlled interchange, fly one time to rear for repair, strip of useful parts and bury, etc.)

    - Design of repairs (i.e., engineering data for tech order (TO) development as well as for forward area design of repairs for damage beyond TO limits.)

    - Repair procedures, time, skills, tools, and materials to perform and check out repairs to determine return-to-combat rate.

- Potential Data Sources:

    - Susceptibility analyses to provide encounter and hit frequencies and locations.

    - Reliability and/or vulnerability analyses to provide failure modes and effects criticality analysis (FMECA) data.

    - Vulnerability analyses to provide damage modes and effects analysis (DMEA) data.

    - Vulnerability analyses to provide information related to survivable damage.

    - Maintenance and repair timeline analyses to assess repair procedures, skills requirements, materials, equipment/tools, and elapsed time to repair.

    - Development Testing & Evaluation to provide system design and vulnerability test data for damage severity, serviceability, triage, and repair technique determination.

    - Live fire testing to provide more realistic damage data than development tests as well as information for repair procedure analysis based on actual system repair.

    - Maintainability testing/demonstration for verification of timeline analysis data.

    - Operational Test & Evaluation to assess BDR procedures conducted under field conditions.

    - Military training exercises to provide more realistic BDR procedures evaluation and lessons learned.

    - Combat then provides the ultimate BDR analysis verification and lessons learned data. The current problem is that there are no provisions for collecting and preserving combat data in a form useful for evaluating BDR adequately.

- Uses of BDR Data:
  - Base operations modeling (manpower, skills, materials, equipment, sortie generation, and maintenance or repair backlog)
  - Spares requirements analysis
  - Cost and operational effectiveness analysis (COEA)
  - Campaign/wargame analysis and simulation

APPENDIX D - DISCUSSION ITEMS for AIRCRAFT BDR METHODOLOGY DEVELOPMENT (WORKSHOP FOLLOW-UP)

This paper outlines discussion items to be used in meetings and interviews with organizations and individuals as follow-up to the Joint Service Aircraft BDR Analysis Methodology Workshop sponsored by the JTCG/AS. These items are grouped into several categories to accommodate discussions with the various specialists involved in BDR related disciplines. These categories include:

I. VULNERABILITY REDUCTION TECHNOLOGY/BDR INTERFACE

Vulnerability reduction (VR) technology is of particular importance to BDR methodology development, because increased system capability to withstand threat weapon effects and still retain some level of mission capability, the objective of implementing VR technology, will result in recovery of more damaged aircraft and, most likely, more severely damaged aircraft which will need repair before the next mission. Simply stated, implementation of VR technology inherently increases the importance of BDR. Therefore, BDR analysis methodology development needs to take into consideration both VR technology development and analysis methods (models or procedures used, parameters assessed, and verification methods).

The objectives of interviews with members of the technology development community specifically involved in VR, including the various Committees under the JTCG/AS Vulnerability Reduction Subgroup (VRS), are to:

1) Identify the advanced technologies with which BDR analysts and designers will have to deal

2) Establish the likelihood of having to deal with these advanced technologies

3) Gain insights to the unique BDR related considerations associated with these technologies.

4) Identify potential opportunities for VR and BDR communities to coordinate efforts and integrate projects to mutual benefit

Discussion Items:

1. What is the real state-of-the-art (SOA) of "advanced" technologies (e.g., advanced composites, fiber optics, reconfigurable control systems, etc.) and their VR potential? Examples of isues to address include:

- Acceptance by primes, aircraft users (DoD & commercial)

  > Thermoset composites SOA

  > Thermoplastic composites SOA

  .

  (other technologies as identified)

  .

  .

2. What is the SOA of repair capabilities for these "advanced" technologies? Examples of issues to address include:

- Permanent repair & BDR

  > Thermosets

  > Thermoplastics

  .

  (other technologies as identified)

  .

  .

3. What vulnerability "assessment" methods/models do subsystem designers/engineers (e.g., structures, flight controls, propulsion, fuel system, crew station, avionics, armament, etc.) use? The supposition here is that subsystem engineers generally deal with analysis methods that relate physical parameters related to component and subsystem performance (e.g., static strength, flow rate, dynamic response, velocity, acceleration, power input/output, heat transfer, etc.) and degradation of these performance capabilities due to threat effects. Both vulnerability and BDR need to convert these parameters to overall system response to threat effects [e.g., probability of kill given a hit ($P_{K/H}$) for a specified kill category, vulnerable area, "survivable" damage levels, repair reqirements, post-repair performance capabilities, etc.]. In order to integrate BDR into the design process, we need to relate BDR methodology development to logical extensions of the analysis methods used by system designers/engineers in their asessment of damage levels and threat effects on the components and subsystems they develop.

1) For example, Project VS-9-02 refers to "characterizing damage in evaluating extent of damage and effect on load carrying capability."

   - What are the specific parameters for this characterization?

   - How are these parameters used to "improve" design for vulnerability reduction?

2) What are the possibilities for extending these parameters or treating them differently to address BDR (e.g., damage "assessment" versus vulnerability "assessment")?

4. What are thoughts on how to convert subsystem (e.g., structures, flight controls, propulsion and power, fuel, crew station, etc.) vulnerability "assessment" results to $P_{K/H}$ inputs for aircraft vulnerability "assessment"? That is, how is "effect on load carrying capability" converted to $P_{K/H}$? The same issue should be addressed for VR parameters for all subsystems.

1) How are the different "Kill Categories" (e.g., K, A, B, C, attrition, mission abort, prevent take-off, etc.) accounted for in the subsystem vulnerability assessment? This item is closely related to the damage state vulnerability analysis methodology being developed by Army Research Laboratory (ARL) where "degraded state capabilities" are defined as intermediate characteristics/parameters between physically observable parameters (e.g., "remaining load carrying capability) and Kill Categories.

5. What BDR assessment and design aids (tools) are available or in development to enhance capabilities for damage diagnosis and post-repair check-out (e.g., USAF/WL and NAWC/AD programs for structural BDR aids)?

1) Follow-on development of the two cited structural BDR aids has been proposed in conjunction with an F/A-18 wing BDR project.

   - Are there other "assessment aids" in development?

   - Could these aids/tools be exercised in VRS projects?

6. What are some possible approaches for integrating BDR into outyear VR technology projects? Some of the mechanisms for coordination of approaches include:

- Joint (VR Subgroup/BDR Committee) meetings

- Joint projects

- Charter revisions (general statements probably exist) (Directory & Admin. Hdbk. don't really direct inter-subgroup coordination. Seems to be left to the Central Office.)

- Workshops/Conferences/Symposia

II. CONSIDERATIONS for BDR in LIVE FIRE TESTING:

- CONGRESSIONALLY MANDATED LIVE FIRE TEST (LFT)
- JOINT LIVE FIRE (JLF)
- DEVELOPMENT TEST & EVALUATION (DT&E) for SURVIVABILITY

Similarly to the case of vulnerability reduction technology and its assessment, BDR analysis methodology development, particularly the BDR database development aspects, should be closely coordinated and integrated with the various live fire test programs for survivability evaluation. These programs currently concentrate almost exclusively on planning for and collecting data related to component, subsystem, and/or system vulnerability. Significant amounts of available BDR data are lost because test planning ignores the database development requirements for BDR. For the most part, BDR is considered only as a specimen preservation and life-extension activity.

Provided herewith is an outline of considerations for discussing BDR as an item which would significantly enhance the value of live fire testing (LFT, JLF, and survivability enhancement DT&E) by providing explicit objectives, logical test preparations, realistic (simulated) field environment for accomplishing repairs, data gathering, post test analysis/evaluation, and documentation of results (including conclusions and recommendations) related specifically to BDR. **(This is a cursory outline to serve as an example. It is recommended that a formal interface be established to include BDR in T&E.)**

Discussion Items:

1. TEST PLANNING:
(Start by having BDR people involved from the beginning)

1) Include BDR in test objectives
(including specific objectives for BDR testing)

2) Identify BDR data requirements and recording procedures

3) Identify test resources for BDR

4) Make BDR part of the test schedule
(including reporting)

2. PRE-TEST PREPARATIONS:
(Be as disciplined in preparations for BDR as for vulnerability evaluation)

1) Damage prediction (What are we going to have to fix?)

2) Identify repair technique(s) to be tested/"tried"

3) Put "repairers" and their "kits" in place for the testing

3. TESTING:
(Do it like it would be done in the field.)

1) Have BDR assessors do assessment along with "vulnerability assessors"

2) "Engineer" the repair(s) based on available "resources" (repairers & kits)

3) Perform the repair(s) per the Test Plan (as closely as logically practical)

4) Perform post-repair check-out/testing to verify repair "quality"

4. DATA RECORDING:

1) Record the data as specified in the Test Plan (Details are yet to be itemized, but a starting point would be the forms developed for COARP/CDRP)

2) Formalize the BDR data preservation as part of raw test data for each test event

5. EVALUATION/ANALYSIS:

1) Analyze BDR test results and compare to "predicted" BDR

2) Provide an evaluation of the repairability of the "test specimen" and effectiveness of the "technique(s)"

6. REPORTING:

1) Put a BDR section in the test report (event by event <u>and</u> overall results - just like the vulnerability reporting procedures)

2) Document BDR conclusions and recommendations

III. ANALYSIS

This section consists of two parts. PART 1. is directed toward gaining more detailed information as follow-up to the previously convened workshop on aircraft BDR analysis methodology. PART 2. is directed toward documenting the current status of Service unique BDR analysis methods.

PART 1.- FOLLOW-UP to JOINT SERVICE AIRCRAFT BDR ANALYSIS METHODOLOGY WORKSHOP

The July 1992 BDR analysis methodology workshop was conducted because there were no DoD recognized BDR analysis methods and the best way to start developing them was to bring together analysts and engineers from the Services associated with the disciplines most closely related to BDR (survivability and integrated logistics support). A major conclusion drawn from the July 1992 workshop was that quantification of BDR could be accomplished through logical extensions of existing survivability and logistics support analysis (LSA) methodologies. The items identified in this section are intended to provide the basis for discussions/interviews with analysts/engineers who perform detailed survivability (susceptibility and vulnerability) and logistics support (reliability, maintainability, and availability) analyses. The primary objective of these discussions is to document what these extensions are/should be in sufficient detail to define work packages and resource requirements for developing DoD recognized BDR analysis methods.

BDR analysis related parameters and/or information have been identified and grouped under the various analysis categories assumed to be most closely related to the BDR parameter. Analysts are asked to identify and describe the mathematical model(s) and/or analysis procedure(s) they use and make the following determinations:

- Can the existing models or procedures produce the required information, either directly or with logical extension? If with extensions, can you provide an analysis flow diagram defining these extensions?

- What are the currently analyzed parameters most closely related to the desired BDR related parameters? (e.g., probability of hit, area removed, peacetime failure rate for sparing, repair time for permanent repair, etc.)

- For a "typical" analysis that you currently perform on a system:

    1) What model(s) are used?

    2) When (in the system acquisition life cycle) is the analysis done

    3) How long does it take (calendar time)?

    4) What does it cost (manyears/dollars)?

    5) What would be your estimate of the additional resources (time, manyears, dollars) required to include the BDR information?

Discussion Items:

The following categories of analyses and BDR related parameters/information are provided as guidance for addressing the above questions:

1. Susceptibility Analysis:

    1) Frequency of hit/damage (Hits per sortie, hits per hour.)

    2) Aspect of hit [From what direction(s) does damage mechanism come?]

        a. Damage direction distribution

    3) Damage location(s) by "encounter" (Where do you get hit?)

        a. Damage location distribution

2. Vulnerability Analysis:

    1) Identify non-vulnerable areas (for various Kill Categories/degraded performance capabilities)

    2) Damage prediction

        a. What physical damage is sustained (Holed, severed, cracked, heated/melted, buckled, electronic burn-out, electronic upset,)

        b. Extent of damage (Hole size, disbond/delaminated area, heat damaged area, temporary damage)

    3) Remaining capability

        a. Remaining strength, life, functional capability

3. Repair Analysis [related to logistics support analysis (LSA) and logistics support analysis record (LSAR)]

1) BDR time-line analysis (comparable to peacetime maintenance time-line analysis)

2) BDR task analysis (detailed task descriptions similar to maintenance task analysis)

3) Parallel/concurrent and/or serial/sequential task accomplishment

4. Supportability Analysis:

1) BDR manpower requirements (skills, number of technicians/artisans, time to repair)

2) Tools/equipment required for BDR (kits, special tools, heavy lift/handling equipment, damage assessment hardware/software (NDI/NDE/NDT), post repair check-out equipment required)

3) Materials for BDR (stock/bulk materials)

4) Spare parts/assemblies for BDR

5) Repair parts for BDR

PART 2.- CURRENTLY AVAILABLE BDR ANALYSIS METHODS

Although, as noted in PART 1., DoD-wide recognized BDR analysis techniques do not exist, the Services do possess their own, or are developing, methods to assess various aspects of BDR. In order to gather the most complete information on the current status of BDR analysis methodology, these Service specific methodologies should be addressed separately.

Discussion Items:

1. What mathematical models and/or analysis procedures are in place, or under development, to analyze BDR? Which of the following aspects of BDR do these models/procedures cover:

   1) Damage prediction (frequency, severity, location)

   2) System response to survivable damage (remaining capability) to facilitate triage

   3) Repair analysis:

      - Permanent and/or temporary repair
      - Resources required (manpower, skills, parts, materials, tools)
      - Repair tasks (sequence of procedures, concurrent/sequential performance)
      - Repair time (manhours, clock time, down time)
      - Return to combat rate

   4) Spares requirements for BDR

   5) System design for BDR enhancement

2. What is the status of the models/procedures? (e.g.,considered to be mature, documented, in development, planned.)

3. At what point in the acquisition life cycle is the methodology applied or intended to be applied?

4. What are input data requirements and what are the sources of input? (e.g., established databases, test data, combat data, analytical data, expert judgement)

5. If the methodology has been used previously, what systems have been analyzed? List of available reports.

6. List of ongoing and planned systems to be analyzed.

7. What resources are required to perform a "typical" BDR analysis (how ever you define "typical" for the above items)? Resource requirements might include:

- Software (model(s) and documentation)

- Hardware (computer/work station)

- Personnel (skills, manhours, government and/or contract support)

- Time (a typical schedule if available)

- "Other"

8. What are the strengths, weaknesses, and/or additional recommended developments associated with the current BDR analysis methodology you use or are developing?

IV. DATABASE DEVELOPMENT/MANAGEMENT

The discussion items listed in this section are to be addressed as they are related to the data and databases associated with survivability and/or LSA methodologies currently used. Since BDR databases may be logical extensions of, or supplements to, these existing databases, it is important to understand their structure, methods of populating, quality, extent, and adaptability for accommodating BDR data.

Discussion Items:

1. What are your analytical data sources? (i.e., input data derived from analysis/simulation)

    1) Models, simulations, or procedures used to derive data

    2) "Accreditation" status of source

2. What are your test derived data sources? (i.e., input data derived from tests; either development, qualification, simulated damage, or live fire damage tests)

    1) Do you use Combat Data Reporting Program (CDRP)-type forms to document test events?

3. To what extent do you use actual combat data? What is your source? (i.e., name of database and location)

    1) Are CDRP forms (or other combat damage/loss data collection forms) published and used?

    2) Are standard maintenance forms [66-1 (USAF), 3M (USN), ? (USA)] used to collect and store combat damage/loss data?

    3) What other field reports generated during wartime might you use as input to your LSA or survivability analysis?

    4) What credibility do you attach to this data?

4. Do you use Safety data (mid-air collisions, crash investigations, ground operations collisions) as input to your analyses?

5. What peacetime maintenance databases and standard forms do you use? (samples are requested)

    1) Are these databases current, accurate, adaptable for extension to BDR?

6. What is your source for system configuration, design, and functional data?

1) Engineering data sources [e.g., loads, limits of capability, reliability, computer aided design and computer aided manufacturing (CAD/CAM) systems, computer-aided acquisition and logistics support (CALS), etc.)

2) Configuration data sources [e.g., solid modeling, CAD/CAM, CALS, etc.]

3) Functional criticality data sources [e.g., failure modes and effects analysis (FMEA), failure modes and effects criticality analysis (FMECA), damage modes and effects analysis (DMEA), failure analysis logic tree (FALT), fault tree analysis, hazard analysis, etc.]

7. What recommendations do you have for development of extensions to the databases and/or data sources you use for including considerations for BDR?

V. COMBAT MAINTENANCE

The discussion items listed in this section are intended to elicit information for development of the methodology to quantify maintenance and repair of combat damaged systems under wartime operating conditions. Some might argue that by definition the routine operations of Military Services automatically address wartime conditions. We have found this not to be the case. For example:

- Maintenance training does not generally include BDR in some Services because personnel might learn "bad habits" and short-cut established peacetime maintenance procedures.

- Some Services have the policy of augmenting their units in a combat theater with specially trained personnel and BDR "tool and materials kits."

- Bases of operation in a combat theater are not configured and equipped the same as peacetime operating bases.

- Special communications networks and logistics chains are established during wartime.

- Routine sparing policies consider only peacetime operations to establish equipment failure and consumption rates. In fact, many components and subassemblies which would receive frequent damage from enemy action are not even entered in the federal stock numbering (FSN) system for ordering spares.

- In general, the databases that are established, populated, maintained, and used for logistics support (reliability, maintainability, and availability) prediction, tracking, and resource allocation are based on peacetime operations.

That being said, the Services do recognize BDR as a force multiplying factor in wartime. The problem is that low priorities are, and will continue to be, placed on BDR enhancement alternatives unless recognized methodologies and associated databases are developed to realistically quantify BDR requirements and benefits.

Discussion Items:

Focus should be on the "special" aspects of "combat maintenance" and BDR when addressing the following items:

1. Analysis of Manpower/Personnel/Training (MPT) for combat:

   1) Skill levels - How do (would) you define BDR skill levels and identify appropriately "skilled" personnel?

   2) Number of artisans (BDR technicians) - How do (would) you determine the number of BDR artisans required by the Units (either as integral Unit members and/or as augmentees during wartime)?

   3) Training requirements - How do (would) you determine BDR training resource requirements such as:

      - Facilities

      - Curriculum

      - Faculty

      - Training equipment (real systems, simulators, simulations, tools, materials etc.)

      - Personnel accession?

2. How would you perceive Combat Maintenance task and time-line analyses as differing from peacetime analyses? (e.g., Would parallel versus sequential task accomplishment have different policy restrictions during combat?)

3. Are (would) special policies be implemented to alter equipment requirements for BDR as opposed to peacetime maintenance? (e.g., Would line combat maintenance crews be equipped differently to handle some heavy maintenance tasks in combat?)

4. How do (would) you predict materials required for BDR?

   1) Stock/bulk materials

   2) Spares (any expansion of breadth or depth for combat)

   3) Repair parts

5. What methods are used to do Mobilization/Deployment Analysis? This item should address "classical" mobilization and deployment as well as Prepositioning. The following factors are examples of possible considerations:

1) Unit level responsibilities

2) Reserves and Guard responsibilities

3) Augmentation of Units for BDR

4) Heavy maintenance capabilities deployed

5) Depot capabilities available to Field Units either deployed or CONUS-based with quick reaction support (e.g., engineering, manufacturing, diagnostics)

INTERVIEW/VISIT CONTACTS for AIRCRAFT BDR - as of 10/25/93

VISIT LOCATION	ORGANIZATION	CONTACT PERSON	TELEPHONE	FAX	DATES of VISIT	SPECIAL CONSIDERATIONS/COMMENTS
	GOVERNMENT					
PENTAGON	AF/LG	Lt Col ART MORRILL (USAF)	703-697-3523	703-695-9811		Pent. rm. 4A264. Info copy of pkg.
	CNO-N881C5	Maj RODNEY TYLER (USMC)	703-695-4917	703-895-5777		Pent.rm. 2C340. Ltr No. 091(7/6/93)
	ASD(P&L)/WSIAD	MARTY METH	703-697-6833			Pent. rm. 2B322. Ltr No. 087(7/1/93)
	ASD(P&L)/WSIAD	GEORGE DESIDERIO	703-756-8420			Skyline. Ltr No. 084(6/24/93)
	OUSD(A)/TS/AS	AL RAINIS	703-697-8183	703-614-7060		Pent rm. 3E1081. Info copy of pkg.
	OUSD(A)/T&E/L&MP	COL PAUL SEVERANCE	703-697-5733	703-614-9883		Pent. rm. 3D1084. Info copy of pkg.
	OUSD(A)/T&E/A&SP	DICK LEDESMA				Pent rm. 3D1075. Info copy of pkg.
	OUSD(A)/TS/LS	GUS SRADERS	703-697-0638			Pent rm. 3E1049. Info copy of pkg.
WP-AFB/DAYTON, OH	WL/FIVS	DON VOYLS	513-255-6179	513-255-2237	22 APR,21/22 JUL	MOU w/ Armstrong Lab & $ for 5 yrs. Ltr No.073 (6/11/93)
		RALPH LAUZZE	513-255-6823	513-255-2237	22 APR, 21 JUL	JLF II Planning. Ltr No.072 (6/11/93)
		JOHN MURPHY			22 APR,(19 JUL)	C-17 LFT (L.E. fire testing, 6 of 25 done, replica)
		MARTY LENTZ	513-255-6302	513-255-2237	(19 JUL)	JLF & S/V Methods
	WL/FIB	TONY LIZZA			(19 JUL)	
	AFMC/ASC/XR & (F-22)	HUGH GRIFFIS	513-255-2353-2353		(22 JUL)	F-22 S, V, BDR, LFT. Ltr No.074 (6/14/93)
	AFMC/ASC/ALTE	DEBRA BENTLEY	513-255-7917		TBD	On travel-19-30 Jul. Ltr No.090(7/6/93)
	AFMC/ASC/ALTE	Lt Col GEORGE ORR	513-255-2220		22 JUL, 13:00	Covering for D. Bentley. Will contact LSA, cost, modeling people.
	INFO ANALYSIS CENTERS					
	SIDAC	STEVE SCHENK	800-54-SIDAC	513-254-9575	20 APR	AF IAC on Supportability (ILS, LSA, etc.)
	SURVIAC	JOHN VICE	513-255-4840	513-255-9673	19 JUL, 14:30	DoD IAC on Survivability. Ltr No. 068 (6/10/93)
McCLELLAN AFB, CA	SM-ALC/TIED	CAPT PAT O'CONNELL	916-643-3851	916-643-0487	21 JUL @ W-P	Meet after BDR Comm. Mtg. Ltr No. 067 (6/10/93)
	SM-ALC/LATE(F-22)					Prior contact was MSgt Bob Faller (May be deleted)
ALEXANDRIA, VA	AMC (logistics)	TBD				
LEXINGTON, KY	AMC/MRSA(AMXMD)	GAYLE REES	606-293-4237		(Call at end of Jul)	OPR, MIL-STD-1388. Ltr No.078(2 cys)(6/23/93)
APG/ABERDEEN, MD	ARL(AMSRL-SL-DA)	JIM WALBERT	410-278-2608		16 JUN, 08:30	Ltr No. 061(6/9/93)
		LISA ROACH	410-278-2608		16 JUN, 08:30	Ltr No. 062 (6/9/93)
	AMSAA	DAN RALEIGH	410-278-8777	410-278-8776		Needs AMSSA Mgt approval. Pkg drop-6/16/93
		KEN STEINER	410-278-7841			Same situation as Dan Raleigh.
	USA OC&S(ATSL-CD-BDAR)	DICK HOY	410-278-3254	410-278-3477	16 JUN, 08:30	Ltr No. 063 (6/9/93)
Ft EUSTIS, VA	USA ALS	CAPT AL VIGNA	804-878-6855			Suggested for deletion, 5/26/93
	USA ATD(AMSAT-R-TL)	MING-LEUNG LAU	804-878-5620	804-878-5058	21 or 22 JUL	Meet @ W-P(BDR Comm mtg). Ltr No. 069 (6/10/93)
ST. LOUIS, MO	AATCOM	CHARLES READING	314-263-1813	314-263-1473	5 OCT, 8:00(B-105)	Comanche Logistics. Ltr No. 071 (6/11/93)
		DENNIS McGUIRE	314-263-1813			
CHINA LAKE, CA	NAWCWD-C (C218)	TIM HORTON	619-939-3681	619-939-2062		Ltr No.079 (6 cys)(6/23/93)
	NAWCWD-C (C2181)	JOHN MANION	619-939-3383			Postponed to JUL if @ NAVAIR
	NAWCWD-C (C21806)	DAVE HALL	619-927-1297			Postponed to JUL if @ NAVAIR
	NAWCWD-C (C21803)	JOHN HOLTROP	619- 939-3683			
	NAWCWD-C (C2183)	HARDY TYSON	619-927-1244			
	NAWCWD-C (C21803)	AL WEARNER	619-927-1249			
CRYSTAL CITY, VA	NASC (AIR-5165)	BOB TRAKAS	703-692-0411-5671		(JULY)	Ltr No.085 (6/30/93)
	NASC (AIR-5164)	JOHN ALDRIDGE	703-692-8600-5647	703-746-6161	(JULY)	Ltr No. 066 (6/10/93)
	NASC(AIR-41111B1)	LAURIE BACCELLIERI	703-692-0028-4119			Ltr No.086 (6/30/93)
	NAWC/AD	GEORGE TEMKIN	215-441-3764		(JULY)	
MCAS Cherry Pt., NC	NADEP Cherry Point	DOUG WALLING	919-466-8042		(TBD)	Ltr No. 070 (6/10/93)
		LEANNA RADFORD	919-466-7348			Ltr No.077(6/14/93). 28 Sep "ABDR contact is Doug Walling"
SAN DIEGO, CA	NADEP North Island	BERT DEL MAR			(7 JUN) (Bruce)	F/A-18 Depot Repair POC(Bruce will be in area)

INTERVIEW/VISIT CONTACTS for AIRCRAFT BDR - as of 10/25/93

VISIT LOCATION	ORGANIZATION/COMPANY	CONTACT PERSON	TELEPHONE	FAX	DATES of VISIT	SPECIAL CONSIDERATIONS/COMMENTS
	INDUSTRY					
ST. LOUIS, MO	MCAIR	DAVE McMILLAN	314-234-5999		(23 AUG, 13:00)	A/C BDR IR&D, Supportability of LO. Ltr No. 075 (6/14/93)
		RAY ANDERSON	314-233-6457			
		MIKE MEYERS	314-234-8913		(23 AUG, 13:00)	F/A-18 S/V & BDR. Ltr No. 076 (6/14/93)
FT. WORTH, TX	BELL HELI. Textron	JACK JOHNSON	817-280-3506	817-280-8304	28 OCT. 8 AM	V-22 survivability & BDR. Ltr No. 080(6/24/93)/Gateway I,Rm906
PHILA., PA	BOEING HELICOPTER	NICK CARAVASOS	215-591-2301			Survivability & BDR. Ltr No.081(6/24/93)
MARIETTA, GA	LOCKHEED AERO	LARRY STEPHENS	404-494-9117	404-494-9142		F-22 survivability & BDR. Ltr No. 082(6/24/93)
ABERDEEN, MD	SURVICE Engrg	KRIS KELLER/GLENN GILLIS	410-273-7722	410-272-7417	15 JUN, 13:00	Methobology & V-MART planning. Ltr No. 064 (6/9/93)
TOWSON, MD	KETRON Div, Bionetics Corp	JOE BURK	410-583-8386		29 JUL, 10:00	Added by LMI, 6/4/93. Ltr No. 065 (6/9/93)
PICO RIVERA, CA	NORTHROP	LAVELLE MAHOOD	310-948-6760		Pln @San Diego	F/A-18 Vuln. Ltr No.083(6/24/93)
	NORTHROP, B-2 DIV.	WALT DOTSETH	310-942-5388/5398			B-2 Suscep., Vuln., & ABDR (T.O.) Ltr No. 094 (8/18/93)
SEATTLE , WA	BOEING Defense & Space Group	JAMIE CHILDRESS	206-662-0250			Vulnerability testing (F-22). Ltr No.092(7/7/93)
		PHIL ROLL	206-662-3338			Aircraft BDR (F-22). Ltr No.093(7/7/93)
BETHPAGE, NY	GRUMMAN AERO & ELEC GP	VINCENT VOLPE	516-575-9890		Pln @ San Diego	Ltr No. 088(7/6/93)
ALEXANDRIA, VA	INST for DEFENSE ANALYSES	LARRY EUSANIO	703-845-6922			Ltr No. 089(7/6/93)
STRATFORD, CT	SIKORSKY AIRCRAFT	RONALD M. DEXTER	203-384-7050		At SMS Mtg. Atlanta	Recvd survey 9/16/93. Pkg sent 9/29/93

APPENDIX E. - Models, Simulations, and Computing Environments

We encountered a great number of models, simulations, and computing environments during the interview and visit process for establishing an aircraft battle damage repair (BDR) analysis methodology development plan. The following list, with short descriptions, summarizes most of those in use or referenced in our conversations. BDR methodology development needs to address this list and arrive at some practical coordination level in cooperation with those responsible for these survivability and logistics support analysis methods.

- Basic design/geometric description systems:

  - BRL/CAD - Ballistic Research Laboratory/Computer Aided Design suite of computer tools to assist in the generation, validation, and interrogation of solid geometric (3-dimensional)" descriptions of military vehicles. BRL is now part of the Army Research Laboratory (ARL).

  - CATIA - A computer aided design/computer aided manufacturing software system developed by Dassault Aviation and used by many primary airframe manufacturers in the US.

  - MGED - Multi-device Graphics Editor developed by the Army Research Laboratory is a combinatorial solid geometry, interactive graphics editor for describing military vehicles. MGED is used by BRL/CAD in the MUVES environment.

  - FASTGEN (2,3, & 4) - Fast Shotline Generator (versions 2 & 3) is a triangular patch, geometric description model developed by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) and the JTCG/AS. It is used to generate input data for COVART. (FASTGEN 2 & 3 are SURVIAC models.) FASTGEN 4 is a similar model converted to be compatible with geometric models used in other disciplines (e.g., the NASTRAN structural analysis model). FASTGEN 4 is a USAF model currently being used for F-22 analysis.

- Damage prediction/vulnerability analysis:

  - COVART (2, 3, & 4) - Computation of Vulnerable Areas and Repair Times, developed by the JTCG/ME and the JTCG/AS versions 2 & 3), calculates vehicle vulnerable area to single fragments and nonexploding projectiles by summing the contributions of individual components. Version 4 is an Air Force developed model compatible with FASTGEN 4 (see above). COVART 2 is a SURVIAC model. Version 3 is scheduled for SURVIAC.

- HEVART - High Explosive Vulnerable Area and Repair Time, developed by the Army Research Laboratory, calculates vulnerable areas and repair times to contact fused exploding projectiles.

- HEIVAM - High Explosive Incendiary (HEI) Vulnerable Area Model, developed by the Navy for aircraft vulnerable area analysis to HEI projectiles.

- SHAZAM - A point burst vulnerability analysis model developed by the Air Force, primarily for munitions effectiveness analysis (US weapons against threat aircraft).

- JSEM - A JTCG developed model to evaluate results of missile warhead encounters with aircraft. JSEM was developed as a composite of desirable features from previously developed endgame models.

- SCAN & SCANMOD - Computer program for survivability analysis to analyze missile warhead detonations in the proximity of aircraft. Developed by the Navy then modified to SCANMOD to accept other threat types and to provide damage predictions for repair time analysis. (SCAN is a SURVIAC model)

- SQuASH - Stochastic Quantitative Analysis of System Hierarchies is a stochastic point burst vulnerability model developed by the Army Research Laboratory. Oriented toward ground combat vehicles. SQuASH is used in MUVES.

- MAVEN - Modular Aircraft Vulnerability Estimating Module in development by the Army Research Laboratory to be used in MUVES for aircraft vulnerability assessment.

- LELAWS - Low Energy Laser Weapon Simulation, developed by the Army Materiel Systems Analysis Activity, analyzes the probability of aircraft sensor damage when engaged by a low energy laser weapon.

- Physics - Development of aircraft damage predictions based on physical interaction of the threat damage mechanism and the aircraft using first principles of physics.

► Platform survivability (1 on 1, or 1 "blue" versus 1 "red") analysis -

- ALARM - Advanced Low Altitude Radar Model, developed by the Air Force, is a ground based radar simulation for susceptibility assessment of low flying aircraft. (SURVIAC model)

- RADGUNS - Radar-Directed Gun System Simulation, developed by the Foreign Science Technology Center and JTCG/AS, analyzes aircraft

detection, tracking, and shooting performance of an air defense gun system. (SURVIAC model)

- ESAMS - Enhanced Surface-to-Air Missile Simulation, developed by the Air Force and JTCG/AS, is widely used to analyze aircraft encounters with surface-to-air missiles (SAMs). (SURVIAC model)

- IMARS - Integrated Missile and Radar Simulation, developed by the Army Missile and Space Intelligence Center, is a detailed SAM radar and aerodynamics encounter model used to determine missile flight profile and miss distance as it intercepts an aircraft. (SURVIAC model)

- HELIPAC - Helicopter Piloted Air Combat model, analyzes helicopter air-to-air combat with another helicopter of a fixed wing aircraft. (SURVIAC model)

- TRAP - Trajectory Analysis Program, analyzes the encounter between an aircraft shooting a missile at another aircraft. is an aircraft. (SURVIAC model)

► M versus N (multiple "blue" versus multiple "red") analysis -

- AASPEM (MIL AASPEM I & II) - Air-to-Air System Performance Model, developed by the Air Force and the JTCG/AS, analyzes air combat encounters between opposing flights of aircraft (up to 24 aircraft and 75 air-to-air missiles). (SURVIAC model) MIL AASPEM includes man-in-the-loop analysis capability.

- TAC Brawler - Tactical Aircraft air-to-air encounter model, developed by the Air Force, analyzes M versus N air superiority aircraft encounters.

- SUPPRESSOR - Developed by the Air Force to analyze electronic combat and aircraft susceptibility as they fly over air defenses with both sides using modern electronic countermeasures and threat suppression techniques.

- TMAS - Tactical Mission Analysis Simulation, developed by Bell Helicopter/Textron to analyze susceptibility of helicopters and VTOL aircraft flying various missions, including ship-to-shore and return.

- LCOM - Logistics Composite Model, a scenario-based model used by the Air Force to assess sortie generation rate from recovery to take-off. Currently, LCOM does not specifically address combat damage.

- TSAR - Theater Simulation of Airbase Resources, developed by RAND for the Air Force, is a Monte Carlo simulation of airbase operations to assess resource interactions and sortie generation rate.

- TSARINA - TSAR Inputs using Airbase Damage Assessment, generates input to TSAR given airbase damage, an attack on the base with conventional or chemical weapons.

- RQM - Resource Quantification Model, in development by the Air Force, analyzes resource requirements for wartime operations of an air base.

- CASEE - Comprehensive Aircraft Support Effectiveness Evaluation is a level III model used by the Navy to evaluate peacetime supportability of aircraft. Wartime attrition and BDR are not addressed.

- SPARC - Sustainability Predictions for Army Spare Component Requirements, developed by the Army Materiel Systems Analysis Activity, predicts spares requirements for a specified time in a theater of operation.

- ROTA - Return-to-Combat of Tactical Aircraft model, proprietary model developed by Alpha Research Corp., analyzes the effect of various levels of BDR capability on sortie generation rate, maintenance or repair backlog, and effective attrition during a specified time in a theater of operation.

► Force level analysis -

- THUNDER - An air combat campaign model used by the Air Force. THUNDER uses TAC Brawler as part of its input.

- JANUS - A detailed wargaming facility at Lawrence Livermore National Laboratory used primarily for analyzing ground combat operations of opposing forces. Interactive command and control can be included.

► Computing Environments -

- ACES/Phoenix - Adaptive Combat Environment System with Phoenix graphical user interface, developed by the Air Force Operational Test and Evaluation Center and Strategic Command to incorporate survivability models to evaluate the B-2 aircraft.

- DIME - Digital Integrated Modeling Environment, under development by the JTCG/AS and intended to be the modeling environment entered into SURVIAC. DIME is based on ACES/Phoenix.

- J-MASS - Joint Modeling and Simulation System, under development by the Air Force (funding from Defense Modeling and Simulation Office), is intended to be a standard modeling & simulation environment for the Services.

- MUVES - Modular UNIX-based Vulnerability Estimation Suite is the Army Research Laboratory computing environment into which various vulnerability models (developed or used by ARL) will be placed.

The above list should be considered and coordination initiated where appropriate when defining specific BDR analysis methodology development tasks. The JTCG/AS Survivability Methodology Subgroup and the Logistics Support Analysis Community need to be involved to prioritize the above models, simulations, and computing environments or to add others that they are aware of which should be considered for BDR methodology development.